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Juvenile Sockeye Salmon Population Estimates using Split-beam Hydroacoustics in Susitna Drainage Lakes, Alaska, 2009 to 2012

by

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and

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November 2014

Alaska Department of Fish and Game Divisions of Sport Fish and Commercial Fisheries

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Weights and measures (metric)

centimeter	cm
deciliter	dL
gram	g
hectare	ha
kilogram	kg
kilometer	km
liter	L
meter	m
milliliter	mL
millimeter	mm

Weights and measures (English)

cubic feet per second	ft^3/s
foot	ft
gallon	gal
inch	in
mile	mi
nautical mile	nmi
ounce	oz
pound	lb
quart	qt
yard	yd

Time and temperature

day	d
degrees Celsius	°C
degrees Fahrenheit	°F
degrees kelvin	K
hour	h
minute	min
second	s

Physics and chemistry

all atomic symbols	
alternating current	AC
ampere	A
calorie	cal
direct current	DC
hertz	Hz
horsepower	hp
hydrogen ion activity (negative log of)	pH
parts per million	ppm
parts per thousand	ppt, ‰
volts	V
watts	W

General

Alaska Administrative Code	AAC
all commonly accepted abbreviations	e.g., Mr., Mrs., AM, PM, etc.
all commonly accepted professional titles	e.g., Dr., Ph.D., R.N., etc.
at	@
compass directions:	
east	E
north	N
south	S
west	W
copyright	©
corporate suffixes:	
Company	Co.
Corporation	Corp.
Incorporated	Inc.
Limited	Ltd.
District of Columbia	D.C.
et alii (and others)	et al.
et cetera (and so forth)	etc.
exempli gratia (for example)	e.g.
Federal Information Code	FIC
id est (that is)	i.e.
latitude or longitude	lat or long
monetary symbols (U.S.)	$, ¢
months (tables and figures): first three letters	Jan,...,Dec
registered trademark	®
trademark	™
United States (adjective)	U.S.
United States of America (noun)	USA
U.S.C.	United States Code
U.S. state	use two-letter abbreviations (e.g., AK, WA)

Mathematics, statistics

all standard mathematical signs, symbols and abbreviations	
alternate hypothesis	H_A
base of natural logarithm	*e*
catch per unit effort	CPUE
coefficient of variation	CV
common test statistics	(F, t, χ^2, etc.)
confidence interval	CI
correlation coefficient (multiple)	R
correlation coefficient (simple)	r
covariance	cov
degree (angular)	°
degrees of freedom	df
expected value	*E*
greater than	>
greater than or equal to	≥
harvest per unit effort	HPUE
less than	<
less than or equal to	≤
logarithm (natural)	ln
logarithm (base 10)	log
logarithm (specify base)	$\log_2$, etc.
minute (angular)	'
not significant	NS
null hypothesis	H_O
percent	%
probability	P
probability of a type I error (rejection of the null hypothesis when true)	α
probability of a type II error (acceptance of the null hypothesis when false)	β
second (angular)	"
standard deviation	SD
standard error	SE
variance	
population	Var
sample	var

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JUVENILE SOCKEYE SALMON POPULATION ESTIMATES USING SPLIT-BEAM HYDROACOUSTICS IN SUSITNA DRAINAGE LAKES, ALASKA, 2009 TO 2012

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ABSTRACT

Juvenile sockeye salmon (*Oncorhynchus nerka*) population studies were conducted from 2009 to 2012 on Susitna River drainage lakes that have historically contained rearing sockeye salmon fry. Surveys used split-beam sonar to estimate juvenile pelagic fish abundance and trawl catches to apportion acoustic targets. Species composition and morphological characteristics of enumerated fish were estimated. Trawl catches consisted primarily of sockeye salmon, stickleback (*Gasterosteus cognatus*), whitefish (*Prosopium cylindraceum.*), Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*Oncorhynchus kisutch*) and sculpin (*Cottus* sp.). Total fish abundance estimates widely ranged from 236,679 in Byers Lake (2009) to 6,237,225 in Shell Lake (2009). No pelagic fish were found in Trapper and Redshirt lakes, which have large populations of northern pike (*Esox lucius*). In 2 other lakes that harbor northern pike, no juvenile sockeye salmon were caught in a trawl survey of Caswell Lake, and juvenile sockeye salmon catches in Shell Lake dropped to 0 in 2010 and 2011. Within 8 additional survey lakes, some of which include northern pike, total pelagic fish densities ranged from 0.0713 fish m^{-2} to 3.5007 fish m^{-2}, and juvenile sockeye salmon densities ranged from 0.0008 fry m^{-2} to 0.7841 fry m^{-2}. Sockeye salmon fry mean lengths ranged from 38.0 mm to 87.8 mm. The mean length of sticklebacks varied between 29.7 mm and 47.0 mm. Sculpin were trawl caught in Chelatna, Stephan, and Shell lakes, while whitefish were only caught in Chelatna Lake. Juvenile salmon abundances in Chelatna, Judd, and Larson lakes were estimated during all 4 years of this study. Judd and Chelatna lakes exhibited oscillating patterns in their sockeye populations from year to year, but overall sockeye salmon abundances were stable.

Key words: Alaska, Susitna, Susitna River, hydroacoustics, Pacific salmon *Oncorhynchus* spp., sockeye salmon *Oncorhynchus nerka,* juvenile, fry, split-beam, sonar, townetting, trawl.

INTRODUCTION

During the fall of each year from 2009 to 2012, the Alaska Department of Fish and Game (ADF&G) conducted hydroacoustic and trawl surveys on lakes within the Susitna River drainage (Figure 1) to estimate the abundance, age, and size distribution of juvenile sockeye salmon, *Oncorhynchus nerka.* In addition to juvenile sockeye salmon, abundance and size distributions were also estimated for other pelagic fish species of comparable size.

Originating in the Alaska Range, the Susitna River watershed encompasses 49,210 km^2 and flows southwesterly for approximately 400 km, where it empties into Cook Inlet, west of Anchorage. Historically, the Susitna River drainage, including 3 major tributaries, Yentna, Chulitna, and Talkeetna rivers, contain numerous sockeye salmon nursery lakes and sloughs (Tarbox and Kyle 1989; Thompson et al. 1986). Habitats within this watershed also support large beds of aquatic vegetation conducive to spawning and rearing of northern pike, *Esox lucius* (Rutz 1996). Whitmore et al. (1994) confirmed that northern pike have spread throughout much of the Susitna drainage since they were introduced into the system during the 1950s.

Limited salmon investigations throughout the drainage were conducted during the 1950s and 1960s by United States Fish and Wildlife Service (USFWS) and ADF&G. These studies included juvenile salmon, adult salmon, and lake limnology information but were not well published. Salmon escapements, juvenile estimates, age, weight, and length data were collected more extensively during the 1970s, primarily in response to the proposed Susitna Hydroelectric Project (Friese 1975). Additional anadromous and resident fish population investigations continued into the 1980s. Cook Inlet Aquaculture Association (CIAA) conducted various nutrient enrichment studies and operated several weirs into the 1990s (Fandrei 1994). Beginning in the mainstem of the Susitna River, salmon escapements have been continuously monitored using sonar since the 1970s. The monitoring station was moved to the Yentna River in the 1980s, where escapement monitoring has continued to the present.

Similar studies were conducted in the early to mid-1990s (King and Walker 1997). The initial study assessed relative lake productivity, estimated rearing juvenile sockeye salmon densities, and determined locations for weir sites (Kyle et al. 1994). Acoustic and trawl surveys were conducted on a few lakes in 1994 and 1995 to estimate numbers of pelagic fish species, collect age, weight, and length information, and conduct acoustic target strength (TS) analysis (King and Walker 1997). Funding to develop these studies was not continued.

Since 2005, comprehensive studies conducted by ADF&G and CIAA have examined sockeye salmon production by comparing fall juvenile acoustic surveys, trawl surveys, limnological studies, and smolt and escapement enumerations. These studies suggest a decline of sockeye salmon production among the smaller lakes of the Susitna River watershed, possibly due to the spread of northern pike. To further investigate sockeye production within the Susitna River drainage, the *Susitna Sockeye Salmon Production* project will estimate sockeye salmon survival from potential egg deposition to fall fry and from fall fry to smolt in at least 17 rearing lakes within the Susitna River drainage from 2009 to 2012. Juvenile pelagic fish surveys were conducted where adult salmon weirs had been used the prior year to estimate spawner abundances. Some of these rearing lakes contain invasive northern pike, while some do not. Of the lakes examined by hydroacoustic and trawl surveys, Chelatna, Shell, Trapper, Redshirt, and Whiskey lakes maintain populations of northern pike. Estimates of sockeye salmon production among all these lakes will be used to evaluate escapement goals and potential management actions.

This report describes the fall hydroacoustic survey component of the *Susitna Sockeye Salmon Production* project, which estimated the abundance, age, and size distribution of juvenile sockeye salmon in 12 rearing lakes in the Susitna River drainage.

OBJECTIVES

The goal of the fall fry surveys was to estimate juvenile sockeye salmon abundance in 12 Susitna River rearing lakes (Byers, Caswell, Chelatna, Fish, Judd, Larson, Redshirt, Shell, Stephan, Swan, Trapper, and Whiskey). Specific objectives were to:

1. estimate abundance by species of fish within the pelagic zone of each lake,
2. estimate mean body size and age composition of juvenile sockeye salmon, and
3. estimate mean body size of other juvenile fish.

METHODS

HYDROACOUSTIC SURVEYS

Surveys of sockeye salmon rearing lakes in the Susitna River drainage began in late August and were completed by late September. Fall fry abundances were estimated using methods developed on Skilak and Kenai lakes (Tarbox and Brannian 1995; Tarbox et al. 1999; DeCino and Degan 2000; Decino et al. 2004). A procedure described by MacLennan and Simmonds (1992), was utilized that uses split-beam sonar data in echo integration and a systematic parallel transects sampling design for hydroacoustic surveys.

Field Equipment and Design

Acoustic surveys were conducted using a Biosonics[1] DTX-6000 split-beam echosounder and accompanying Visual Acquisition data collection software (Appendix A). Depth ranges were set to include acceptable data for processing in relation to the varying lake bottom depths or the midwater strata. The transducer was mounted face down to a 1.5 m, 30.4 kg tow body made out of aluminum and weighted with lead for stability. The tow body was connected to a boom by an adjustable length of rope, which was attached either to the towing boat's starboard side or directly in front of the bow. When the echosounder was active, the transducer was towed approximately 1 m below the surface of the water at a rate of 2 m/s. Digital data from the transducer were transmitted directly through a data cable into the echosounder. The echosounder was in direct communication with a weather-resistant laptop computer where the acoustic digital data were collected and stored. A Garmin eTrex Legend global positioning system (GPS) was attached to the sounder to input geo-referenced transect routes as the survey progressed. The laptop computer and acoustic system power was supplied by a 12V battery and inverter.

Transects for lake surveys were based on prior studies by King and Walker (1997). Lakes that had not been surveyed under previous studies followed a similar protocol for transect design. Unless shallow depth zones precluded the placement, transects were evenly spaced on lake maps. Transect end points were entered into a handheld GPS where waypoints were used to create a survey route. Once in the field, the survey route end points were marked with flashing strobe lights. This was accomplished during daylight hours so that transect designs could be adjusted if field conditions did not exactly match map layouts. Hydroacoustic surveys were then implemented during the night, in dark conditions, when the greatest sockeye salmon dispersion occurred. While in the dark, a 4.9 m rubber raft, carrying the acoustic equipment, powered by a 30 hp, 2-stroke motor, was directed along the transect route using the flashing strobe lights and handheld GPS. To allow greater operational efficiency, a 6 m cataraft, powered by two 30 hp, 2-stroke motors replaced the 4.9 m raft in 2012.

Acoustic Analysis

Stored acoustic digital survey data from the laptop were edited using Echoview analysis software. Fish density estimates were computed for each transect and then expanded to each lake's area.

Acoustic data was edited to remove lake bottom echoes and extraneous echo noise. Then, individual targets were processed to estimate in-situ TS and the area backscattering coefficient, sigma (σ), using a macro constructed by Aquacoustics Inc. Transect information was appended to calculate TSs and sigma for each target. Only target echoes that were within +3dB to -3dB off axis from beam center were included. Additionally, large targets (> -40dB) were removed before calculating the average sigma. The number of targets, TSs, and average sigma were compiled into 1 m depth strata (Appendix A). Depth strata containing similar average sigma or stratum-specific sigma were echo-integrated to compute fish densities for each transect (Table 1).

A poststratification method was used to estimate juvenile sockeye salmon abundance in each lake (Cochran 1977). Adjacent transects with similar fish densities were combined to form strata, substantially improving the precision of the estimates. Echo-integration estimates of fish density

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[1] Product names used in this report are included for scientific completeness but do not constitute a product endorsement.

were used to estimate the total number of fish (N_{ij}) for each stratum *i,* based upon transects *j,* and across each depth stratum *k.* N_{ij} consisted of an estimate of the number of fish detected by hydroacoustic gear in both the surface and the midwater depth intervals as described in DeCino and Degan (2000) and DeCino and Willette (2011). The population estimate of the area based on the density of transect *j* component was estimated as

$$\hat{N}_{ij} = a_i \sum_{k=1}^{K} \hat{M}_{ijk}, \tag{1}$$

where a_i represented the surface area (m^2) of area stratum *i*, which was estimated using a planimeter and USGS maps of the Susitna drainage lakes, and M_{ijk} (number/m^2) was the estimated mean fish density in area *i* depth *k* across transect *j*. Depth was the actual detected bottom within depth stratum *k* along each transect if the detected bottom was less than the maximum acoustic range (Appendix A).

Fish abundance for each stratum *i* (N_i) was estimated from the average of the abundances for all transects *J* in the stratum:

$$\hat{N}_i = J^{-1} \sum_{j=1}^{J} \hat{N}_{ij}, \tag{2}$$

with variance

$$v\left(\hat{N}_i\right) = \sum \left(\hat{N}_{ij} - \hat{N}_i\right)^2 (J-1)^{-1} J^{-1}. \tag{3}$$

Fish abundance for the entire lake was estimated by summing the abundance estimates from all strata, and the variance of the abundance was estimated by summing the variances from all strata:

$$\hat{N} = \sum_i \hat{N}_i. \tag{4}$$

with variance

$$v\left(\hat{N}\right) = \sum_i v\left(\hat{N}_i\right). \tag{5}$$

TRAWL SURVEYS

Midwater trawl surveys were conducted in conjunction with the hydroacoustic surveys performed on 12 lakes within the Susitna drainage. These surveys were used to estimate species composition of ensonified targets and to provide mean sizes of juvenile fishes and ages of sockeye salmon.

Field equipment

Midwater trawls measuring either 3 m x 7 m or 4 m x 6 m were utilized in the deeper lakes (Byers, Chelatna, Larson, Judd, and Shell), while a 4 m x 2 m trawl was used in the shallower lakes (Caswell, Fish, Redshirt, Stephan, Swan, Trapper, and Whiskey). Each trawl was constructed of increasingly smaller mesh from the opening to the cod end where the mesh size was 0.3 cm. The 4 m x 6 m trawl, primarily used in 2012, had a different mesh configuration and facilitated a slight increase in towing speed. Trawls were held open by attaching aluminum pipe stock to the top and bottom. Weights were connected to the deep side of the trawl, while buoys were attached to the surface side of the trawl. The aluminum pipes were bridled to towing lines, right and left, approximately 45.7 m long.

Two 4.9 m rafts, powered by 30 hp motors, pulled the tow lines. To stabilize the rafts and maintain a constant opening of the trawls, each raft was connected to the other with 6.1 m long crisscrossed aluminum pipe. In 2012, a single 5.6 m cataraft was employed to pull the same tow lines, powered by two 30 hp motors, simplifying field operations without significant changes to trawl towing performance.

Depths of tows were established by varying lengths of buoy ropes from 1 m to 12 m long. Tow depths and proper deployment of the trawls was verified using a HOBOware data logger attached to either the top or bottom of the trawl. A Garmin eTrex Legend was used to regulate and stabilize individual tow speeds. Towing speed was maintained at approximately 1 m sec^{-1}. Greater speeds were unobtainable due to net resistance, net closure, and net rise in the water column. Variables such as wind direction and available towing space influenced tow speed and tow direction.

Sampling design

A stratified sampling design (Scheaffer et al. 1986; Cochran 1977) with strata established by depth was employed for trawl sampling. The sampling goal for each lake was the number of tows (effort) and not the total number of sockeye salmon captured. The original sampling goal was 300 sockeye salmon or a total of 500 fish of all species per lake. Deeper lakes were sampled from 3 depth strata, and shallower lakes were sampled from 2 depth strata. These goals were difficult to achieve in some cases, while in other cases those sampling levels resulted in an inadequate coverage of the entire lake. The sampling design was refined to specific depths and number of tows. For deeper lakes like Chelatna, Judd, and Larson, sampling was defined to 3 depth strata (0–5 m, 5–10 m, and 10–20 m). Three net tows were conducted in each depth strata. Chelatna Lake was further divided into 2 area strata with 9 net tows in each area. Towing was conducted for a second night if necessary to achieve the sampling goals.

For shallower lakes like Shell, 3 net tows were conducted in 2 depth strata (0–5 m and 5–10 m). Two surface tows and 1 deep (5–10 m) tow were conducted at Caswell and Whiskey lakes due to their smaller size and shallow depths.

On most lakes, trawling was conducted immediately after each hydroacoustic survey in locations and depths as indicated by the distribution of acoustic targets, while also attempting to sample the entire area; however, due to its size and the time needed to conduct a hydroacoustic survey, trawling was conducted on Chelatna Lake the next day. Standard tows were usually 30 minutes in duration; however, in shallow or small lakes, tows were sometimes less than 30 minutes long.

All captured fish were identified and enumerated on site at the end of each tow. Non-salmonid species were individually enumerated from each sampling net dipped from the trawl net until their total number exceeded 500, then they were estimated by counting the number of sampling nets required to clear out the remaining catch. If captured, a random sample of 300 sockeye salmon fry and 100 non-salmonid species were kept for estimation of mean body size and were preserved in 10% buffered formalin solution.

Formalin stabilization of fish samples was allowed for a minimum of 4 weeks before sample processing (Shields and Carlson 1996). Salmonid fork length (nearest 1 mm) and wet weight (nearest 0.1 g) were measured, and scales were collected from 40 mm plus fish (for age determination). Only lengths and weights were measured from non-salmonids.

A 2-stage cluster sampling method was used to estimate species composition and juvenile sockeye salmon abundance for each lake (Appendix B). Species proportions and age compositions, mean lengths, and mean weights of the fry were weighted by the catch in each tow (Scheaffer et al. 1986; Cochran 1977).

RESULTS AND DISCUSSION

From 2009 to 2012, the number of transects for surveys consisted of 15 (Byers Lake); 8 (Caswell Lake); 18 (Chelatna Lake); 6 (Fish Lake); 15 (Larson Lake); 10 (Redshirt Lake); 16 (Shell Lake); 7 (Stephan Lake); 8 (Swan Lake); and 4 (Trapper Lake). There were 6 transects for Judd Lake in 2009 and 2010, with 2 additional transects added in 2011 and 2012. Adjacent transects that were combined for poststratification varied from year to year as fish densities varied from year to year across strata of each lake. Listed transect combinations minimized error (Appendix A).

2009

Total fish abundances estimated by acoustic surveys ranged from 236,679 in Byers Lake to 6,237,225 in Shell Lake. Density ranged from 0.1012 fish m^{-2} in Chelatna Lake to 2.0230 fish m^{-2} in Larson Lake (Table 2).

Sockeye salmon fry populations were highest in Larson Lake (1,899,122) and lowest in Byers Lake (3,757). Juvenile sockeye densities ranged from 0.0012 fry m^{-2} in Shell Lake to 0.7703 fry m^{-2} in Larson Lake (Table 2). In the Shell and Byers lake trawl surveys, only 2 juvenile sockeye were captured in each lake. These results are consistent with previously low sockeye salmon capture rates as indicated by King and Walker (1997) and DeCino and Willette (2014). Low sockeye salmon catches may be due to low sockeye salmon catchability in clear water lakes, which compromised our ability to use trawl-net catches to apportion acoustic estimates of fish abundance to species. Although 2008 adult sockeye salmon weir counts at Shell (2,624) and Byers (1,492) lakes were low, it seems likely that our acoustic fry abundance estimates were biased low, probably due to problems with apportioning sonar abundance estimates to species. The following table indicates the difference between our estimated fall fry abundance and predicted fall fry abundance assuming 2.1% embryo-to-fall fry survival for typical Alaska lakes (Koenings and Kyle 1997).

Year	Life stage abundance	Shell	Byers
2008	Adult spawners	2,624	1,492
2008	Predicted embryos	4,592,000	2,611,000
2009	Predicted fall fry	96,432	54,831
2009	Actual fall fry estimate	5,582	3,097

Approximately 14,578 total fish were caught in trawl surveys, ranging from 27 fish at Stephan Lake to 12,012 fish at Swan Lake (Table 3). Including all lakes, sockeye salmon fry comprised the highest fraction of total catch at Chelatna Lake (96.1%), while the lowest percentage of fry was at Shell Lake (0.1%), (Table 3). Sticklebacks (*Gasterosteus cognatus*) were the predominant non-salmonid fish caught in most lakes, excluding Stephan and Chelatna lakes, ranging from 20.8% at Judd Lake to 99.9% at Shell Lake, while sculpin (*Cottus* sp.) at 40.7% were prevalent at Stephan Lake. Chinook salmon (*O. tshawytscha*), lake trout (*Salvelinus namaycush*), coho salmon (*O. kisutch*) and whitefish (*Prosopium cylindraceum*) were other species present in trawl catches.

Including the small sample size of juvenile sockeye salmon from Byers and Shell lakes, age-0 fry constituted from 87.2% of the fry caught in Judd Lake to 100% of the fry caught in Chelatna, Byers, Shell, Stephan, and Larson lakes. Age-1 fry comprised 12.8% of the juveniles captured in Judd Lake and 3.3% of fry caught in Swan Lake. On average, the largest juveniles were found in Swan Lake at 84.3 mm and 7.1 g, while the smallest fry were found in Judd Lake at 41.2 mm and 0.8 g (Table 4).

Mean lengths of sticklebacks varied from 33.0 mm at Judd and Shell lakes to 36.3 mm in Larson Lake. Mean weights of sticklebacks ranged between 0.3 g at Shell Lake to 0.5 g at Larson Lake (Table 5). The smallest estimated population of stickleback was 129,088 in Judd Lake, and the largest estimated population of stickleback was 6,229,874 in Shell Lake. Whitefish abundance was estimated at 49,829 in Chelatna Lake, and this species was not present in the other lakes as indicated by trawl catches (Table 6). While the number of fish caught at Stephan Lake wasn't high, this lake exhibited the greatest variety of fish species.

Shell Lake's whole water column TS was the smallest at -56.3 dB, while Byers Lake's overall TS of -48.3 dB was the largest. TSs in the upper, near surface, water stratum were smallest at Stephan Lake (-58.4 dB) and largest at Byers Lake's mid to bottom water stratum (-47.3 dB). Average sigma from 2 to 3 depth strata were used to echo integrate population estimates from all the lakes. The values of sigma used to echo integrate each lake's depth strata ranged from 1.44×10^{-6} at Stephan Lake to 1.85×10^{-5} at Byers Lake (Table 1).

2010

Total fish abundances estimated by acoustic surveys ranged from 298,549 in Judd Lake to 2,965,067 in Shell Lake. Density ranged from 0.0713 fish m^{-2} in Chelatna Lake to 1.1324 fish m^{-2} in Fish Lake (Table 2). No pelagic fish were caught in either Redshirt Lake or Trapper Lake despite the presence of 18 acoustic targets in Trapper Lake and 1087 acoustic targets in Redshirt Lake (Appendices A9 and A12). Instead, trawl catches consisted of hundreds of insects of the family Corixidae (common name, water boatmen) in Trapper Lake and thousands of Corixidae in Redshirt Lake. Perhaps the observed acoustic targets in these 2 lakes were insects, but this cannot be confirmed.

Excluding Shell, Trapper, and Redshirt lakes, fry populations were highest in Chelatna Lake (1,081,115) and lowest in Fish Lake (452). Juvenile densities ranged from 0.0008 fry m^{-2} in Fish Lake to 0.1643 fry m^{-2} in Judd Lake (Table 2). Consistent with previous trawl results, 0 juvenile fish were captured in the Shell Lake survey. The 2009 adult sockeye salmon weir count at Shell was 4,961. Since our acoustic fry abundance estimate for Shell Lake may be biased low due to trawl apportionment, the following table indicates the difference between our estimated fall fry abundance and predicted fall fry abundance in Shell Lake assuming a 2.1% embryo-to-fall fry survival.

Year	Lifestage abundance	Shell
2009	Adult spawners	4,961
2009	Predicted embryos	8,681,750
2010	Predicted fall fry	182,317
2010	Actual fall fry estimate	0

Approximately 11,978 total fish were caught in trawl surveys, which ranged from 0 fish at Redshirt and Trapper lakes to 9,360 fish at Fish Lake. Excluding Shell, Redshirt, and Trapper lakes, for reasons mentioned above, the highest percent of fry catch was at Chelatna Lake (89.6%), while the lowest percent of fry (0.1%) was at Fish Lake. Sticklebacks were the predominant non-salmonid fish caught, ranging from 29.6% at Judd Lake to 100% at Shell Lake (Table 3). Coho salmon and whitefish were other species present in trawl catches.

Including the small sample size of juvenile sockeye salmon from Fish Lake, age-0 fry constituted from 71.4% of the fry caught in Fish Lake to 100% of the fry caught in Chelatna and Larson lakes. Age-1 fry comprised 4.9% of the juveniles captured in Judd Lake and 28.6% of the juveniles caught in Fish Lake. The largest average age-0 juveniles were found in Fish Lake at 65 mm and 3.4 g, while the smallest average fry were in Judd Lake at 38.0 mm and 0.7 g (Table 4).

Mean lengths of sticklebacks varied from 33.7 mm (0.4 g) in Larson Lake to 47.0 mm (1.0 g) in Fish Lake (Table 5). Stickleback abundance estimated for Chelatna, Trapper, and Redshirt lakes was 0; the estimated population of sticklebacks was 88,490 in Judd Lake; and the largest estimated population of stickleback was 2,965,067 in Shell Lake (Table 6). Whitefish were the only other significant fish species estimated at 125,584 in Chelatna Lake.

Shell Lake's whole water column TS was the smallest at -55.6 dB, while Larson Lake's overall TS of -50.2 dB was the largest (Table 1). TSs in the upper, near surface, water stratum were smallest at Larson Lake (-56.9 dB) and largest at Larson Lake mid to bottom water stratum (-48.8 dB). Average sigma from 2 to 3 depth strata were used to echo integrate population estimates from all the lakes. The values of sigma used to echo integrate each lake's depth strata ranged from 2.06 x 10^{-6} at Larson Lake to 1.30 x 10^{-5} also at Larson Lake.

2011

Total fish abundances estimated by acoustic surveys ranged from 926,291 in Judd Lake to 3,839,194 in Whiskey Lake (Table 2). Density ranged from 0.1137 fish m^{-2} in Chelatna Lake to 3.5007 fish m^{-2} in Whiskey Lake (Table 2). Whiskey Lake had the highest variance among the lakes, possibly due to high densities of stickleback, vegetative matter, and large transect segments over shallow depths.

Sockeye salmon fry populations were highest in Chelatna Lake (1,858,125) and lowest in Whiskey Lake (1,612). Juvenile densities ranged from 0.0015 fry m^{-2} in Whiskey Lake to 0.5169 fry m^{-2} in Judd Lake. No juveniles were captured in the Caswell Lake trawl survey. No previous trawl records are known for Caswell Lake. Consistent with previous trawl results, no juveniles were captured in the Shell Lake survey. The 2010 adult sockeye salmon weir counts were 2,223 at Shell Lake and 0 at Caswell Lake (Table 2). Since our acoustic fry abundance estimate for Shell Lake may be biased low due to trawl apportionment, the following table indicates the difference between our estimated fall fry abundance and predicted fall fry abundance in Shell Lake assuming 2.1% embryo-to-fall fry survival.

Year	Life stage abundance	Shell
2010	Adult spawners	2,223
2010	Predicted embryos	3,890,250
2011	Predicted fall fry	81,695
2011	Actual fall fry estimate	0

Approximately 63,822 total fish were caught in trawl surveys, ranging from 454 fish at Judd Lake to 50,021 fish at Whiskey Lake. Excluding Shell and Caswell lakes, fry comprised the highest percent of total catch at Chelatna Lake (96.6%), while the lowest percent (0.042%) of fry was at Whiskey Lake (Table 3). Excluding Chelatna Lake, sticklebacks were the predominant non-salmonid fish caught in most lakes, ranging from 28.4% at Judd Lake to 100% at Caswell Lake. Sculpin, coho salmon, and whitefish were other species present in trawl catches.

Including the small sample size of juvenile sockeye salmon from Whiskey Lake, age-0 fry constituted from 65.8% of the fry caught in Judd Lake to 100% of the fry caught in Chelatna Lake. Age-1 fry comprised 34.2% of the juveniles captured in Judd Lake and 9.8% of fry caught in Larson Lake. The largest juveniles were found in Larson Lake at 87.8 mm and 8.3 g, while the smallest average fry were in Judd Lake at 50.3 mm and 1.4 g (Table 4).

Mean lengths of sticklebacks varied from 29.7 mm at Caswell Lake to 45.2 mm in Judd Lake (Table 5). Mean weights of sticklebacks ranged between 0.3 g at Caswell and Larson lakes to 1.1 g at Judd Lake. The smallest estimated population of stickleback was 263,197 in Judd Lake, and the largest estimated population of stickleback was 3,837,582 in Whiskey Lake (Table 6). Whitefish abundance was estimated at 62,498 in Chelatna Lake, and this species was not present in the other lakes as indicated by trawl catches. The sculpin abundance estimate in Shell Lake was 88,937. Small populations of coho salmon were found in Chelatna Lake (2,404) and Judd Lake (2,040; Table 6).

Caswell Lake's whole water column TS was the smallest at -56.3 dB, while Chelatna Lake's overall TS of -50.3 dB was the largest (Table 1). TSs in the upper, near surface, water stratum were smallest at Caswell Lake (-58.1 dB) and largest at Chelatna Lake's mid to bottom water stratum (-48.9 dB). Average sigma from 2 to 3 depth strata were used to echo integrate population estimates from all the lakes. The values of sigma used to echo integrate each lake's depth strata ranged from 1.56×10^{-6} at Caswell Lake to 1.28×10^{-5} at Chelatna Lake (Table 1).

2012

Total fish abundances estimated by acoustic surveys ranged from 835,279 in Judd Lake to 2,804,316 in Larson Lake (Table 2). Density ranged from 0.0859 fish m^{-2} in Chelatna Lake to 1.1579 fish m^{-2} in Larson Lake. Sockeye fry populations were highest in Chelatna Lake (1,453,065) and lowest in Larson Lake (366,489). Juvenile sockeye salmon densities ranged from 0.0859 fry m^{-2} in Chelatna Lake to 0.519 fry m^{-2} in Judd Lake (Table 2).

Approximately 3,077 total fish were caught in trawl surveys, ranging from 407 fish at Chelatna Lake to 1,637 fish at Judd Lake (Table 3). Sockeye salmon fry comprised the highest percent of total catch in Chelatna and Judd lakes, while the lowest percent of fry was at Larson Lake (13.1%), (Table 3). Sticklebacks, unlike most sampling years, were the only non-salmonid fish caught in Judd (20.5%) and Larson lakes (86.9%).

Juvenile sockeye salmon collected from each of the 3 lakes revealed that age-0 fry constituted from 92.9% of the fry caught in Judd Lake to 100% of the fry caught in Chelatna Lake (Table 4). Age-1 fry comprised 7.1% of the juveniles captured in Judd Lake and 1.5% of fry caught in Larson Lake. The largest juveniles were found in Larson Lake at 63.0 mm and 3.0 g, while the smallest average fry were in Judd Lake at 39.0 mm and 0.6 g (Table 4).

Mean lengths of sticklebacks varied from 33.5 mm at Larson Lake to 37.8 mm in Judd Lake (Table 5). Mean weights of sticklebacks ranged between 0.4 g at Larson Lake to 0.7 g at Judd Lake. The smallest estimated population of stickleback was 171,444 in Judd Lake, and the largest estimated population of stickleback was 2,437,828 in Larson Lake (Table 6).

Judd Lake's whole water column TS was the smallest at -54.9 dB, while Chelatna Lake's overall TS of -49.1 dB was the largest (Table 1). TSs in the upper, near surface, water stratum were smallest at Larson Lake (-56.8 dB) and largest at Chelatna Lake's mid to bottom water stratum (-49.5 dB). Average sigma from 2 to 3 depth strata were used to echo integrate population estimates from all the lakes. The values of sigma used to echo integrate each lake's depth strata ranged from 2.10×10^{-6} at Larson Lake to 1.47×10^{-5} at Chelatna Lake (Table 1).

Summary

These juvenile fish abundance estimates are part of several simultaneous investigations of sockeye salmon production conducted by ADF&G and CIAA. These juvenile population abundance estimates will be analyzed along with limnology, sockeye smolt, and adult salmon data to further investigate sockeye salmon production in the Susitna drainage. Fall juvenile pelagic fish surveys were conducted at lakes where spawner abundances had been estimated the previous year using adult salmon weirs.

Fall fry surveys were conducted every year at Chelatna, Judd, Shell, and Larson lakes, since these 4 lakes provide key indices of Susitna River sockeye salmon production, and all but Shell Lake have sustainable escapement goals (Fair et al. 2009). Fall population estimates along with age, weight, and length data are useful for evaluating smolt abundance estimates and future returns of sockeye salmon.

No adult salmon were counted through weirs operated at Redshirt, Trapper, Caswell, and Sucker lakes. It was necessary to conduct fall surveys to confirm the existence or non-existence of salmonids in these lakes where sockeye salmon populations once existed (Rutz 1999). Sucker Lake was not included in fall surveys due to its shallow depths (< 2 meters) and vegetative growth covering the entire lake. However, the adult salmon weir crew observed a significant population of northern pike in Sucker Lake. Even though heavily populated with northern pike, adult humpback whitefish (*Coregonus pidschian*) and longnose suckers (*Catostomus catostomus*) were found in Redshirt and Trapper lakes during northern pike surveys in 2011. In addition, 1 large rainbow trout (*Oncorhynchus mykiss*) was caught and released in Trapper Lake. In 2009 there were 7 Chinook salmon observed in Trapper Creek during an aerial survey, and 1 salmonid was video monitored swimming upstream toward Redshirt Lake in 2010. During surveys of Caswell Lake in 2011, coho salmon juveniles were observed in Caswell Creek.

Beaver dams have also restricted salmonid access to Redshirt, Trapper, Sucker, Caswell, and Shell lakes. CIAA has successfully passed sockeye salmon through "notched" beaver dams on Shell Creek each year during this study. Chelatna, Whiskey, and Shell lakes contain populations of northern pike mixed with other finfish populations. Chelatna Lake is a large glacially-influenced system with limited northern pike habitat.

Larson, Fish, Swan, Whiskey, Shell, Caswell, Judd, and Byers lakes have large populations of stickleback. In lakes where there were catchable fry populations and higher densities of targets (Judd, Larson, Fish, Swan, and Whiskey), there was a trend toward increased percentages of age-1 fall fry. However, in Larson Lake this pattern was only apparent in 2 of 4 years (2009–2012). In lakes in which there was lower total fish density (Chelatna, Stephan, and Byers), only age-0 fall fry were caught in the pelagic zone. Of these 3 lakes, Byers was the only lake with significant populations of sticklebacks. Although age-1 fry were not found in pelagic trawls, these lakes have produced small numbers of age-2 salmon smolt. Thus, competition with large stickleback populations or higher fish densities may reduce fry growth, causing them to hold over for an additional year of rearing in the lake.

Of the 12 lakes examined in this study, 8 contained large populations of sticklebacks. Based upon King and Walker's (1997) studies, mean TSs of sticklebacks and sockeye salmon fry overlap. The range of mean TSs at Judd Lake did not exceed 3 dB during this 4-year study. During this same time frame, sockeye proportions moderately fluctuated between 70.4% and 79.5% of trawl catches. Mean sockeye salmon lengths varied between 39.1 mm and 55.8 mm, while stickleback mean lengths ranged between 33.0 mm and 45.2 mm with the largest lengths for stickleback and sockeye salmon both occurring in 2011. Pelagic fish population estimates for Judd Lake over the course of these 4 years indicate that stickleback and sockeye salmon populations both rise and fall together (Figure 2). This same pattern exists when population estimates from 2005 to 2008 are also included (DeCino and Willette 2014). Not only have the sockeye salmon and stickleback populations fluctuated together, but they have also exhibited a biennial cycle from 2005 to 2012. To some degree, both species may be regulated by the same limiting factor.

Sockeye salmon fry mean sizes in Judd Lake were positively correlated with total fish abundance between 2009 and 2012 (Tables 2 and 4), but these parameters were negatively correlated between 1993 and 1995 (Appendix C). Judd Lake maintains populations of age-0 and age-1 fall fry, and during the last 4 years the proportion of age-1 fry ranged from 4.9 to 34.1%. Between 2009 and 2012, age-0 fry mean lengths were positively correlated with age-1 fry mean lengths, and the proportion of age-1 fry was positively correlated with total fish abundance, but these correlations were not evident in 2005–2008.

In Judd Lake, pelagic fish densities from surface to bottom exhibited a more even distribution compared to other lakes examined in the Susitna drainage (Appendix D). Other lakes exhibited a rapidly declining fish density to depths of 20 m or greater, whereas vertical distributions of fish in Judd Lake was bimodal in 2009–2011 but not in 2012.

Sockeye salmon fry densities in Judd Lake were consistently higher than other lakes in Upper Cook Inlet, and its fry were among the smallest. Considering its high fish density and low trophic status (Kyle et al. 1994), it is not surprising that fry sizes were small indicating fish densities were near rearing capacity. Analysis of limnological and adult escapement data may reveal the cause of these observations.

Juvenile fish catches were probably a fairly accurate measure of the actual species composition in Judd Lake (King and Walker 1997). Catch sample sizes have been consistently higher in Judd Lake than other lakes. Sockeye salmon catches in 2012 were the highest to date for Judd Lake, though trawl catch rates for Chelatna and Larson lakes did not differ significantly from historical catch rates despite the change in trawl net design. As mentioned previously, low sockeye trawl catches may indicate sampling error in using trawl techniques due to low sockeye catchability. If Judd Lake trawl catches provide accurate species proportions, then trawl catches in other lakes with similar characteristics may also provide accurate species proportions. Judd Lake is shaped like a bowl with little aquatic vegetation, low trophic status, and limited shallow areas (i.e. the lake's salmonid rearing habitat is primarily pelagic). Chelatna and Larson lakes are similar to some degree, whereas other lakes in this study have proportionately more shallow areas with aquatic vegetation where sticklebacks are more abundant (Appendix E).

We may need to modify our townetting methods to increase the accuracy of our species composition estimates. Species apportionment in lakes where sockeye salmon fry, sticklebacks, and whitefish coexist may become complicated by sockeye salmon fry intermingling between pelagic and shallow zones. Apportionment problems will be inherent when proportions of species vary between years and the species of interest (sockeye) is a small fraction of the total population and their rearing habitats vary.

Shell Lake has had consistently large populations of stickleback as determined by trawl catches. It is not known whether competition with stickleback is affecting sockeye salmon production in Shell Lake, but, adult sockeye salmon returns and subsequent smolt migrations have been trending downward since 2006. Shell Lake also has large northern pike populations, beaver dams restricting access to spawning grounds, and parasitic infestations. *Loma salmonae, Tetracapsuloides bryosalmonae,* and the nematode *Philonema* sp. have all been contributing to pre-spawn mortalities of adult sockeye salmon during the last several years (Ferguson Bentz, Fish Health Investigator, ADF&G Pathology Laboratory, Accession No: 2013-0027, personal communication).

Trawl catches from Larson Lake surveys have resulted in variable proportions of sockeye salmon and stickleback. Subsequent smolt abundance estimates (Gary Fandrei, Cook Inlet Aquaculture Association, personal communication, Soldotna) have not correlated with fall fry abundances, suggesting problems with species apportionment using trawl catches in Larson Lake. Juvenile sockeye salmon captured in Larson Lake have been consistently larger than sockeye captured in Judd or Chelatna lakes, so their large size may have contributed to problems with species apportionment.

Hydroacoustic estimates of sockeye salmon abundance in Chelatna Lake were likely more accurate than in Larson Lake, since sockeye salmon fry comprised 89.6–100% of trawl catches. Mean sizes of age-0 fry in Chelatna Lake were positively correlated with total fish and sockeye salmon abundance estimates between 2009 and 2012, but negatively correlated with fish abundances between 1993 and 1995 (Appendix C). The 1993 abundance estimates were similar to recent estimates, but the 1994 and 1995 estimates were significantly higher. Between 1983 and 1988, CIAA and ADF&G investigated the potential of nutrient enrichment to enhance salmon production in Chelatna Lake. Based upon these studies, it was concluded that Chelatna Lake was not meeting its potential in sockeye salmon production due to spawning limitations (Fandrei 1995). From 1990 to 1995 Chelatna Lake was stocked with hatchery reared sockeye salmon fry. The stocking program may account for the higher abundance estimates and contrasting results in fish sizes obtained in the 1990s.

Overall, juvenile sockeye salmon abundances in Chelatna and Judd lakes have exhibited an oscillating pattern of abundances with the 2 stocks coming into phase in 2009 (Figures 3 and 4). Chelatna and Judd lakes likely account for about 50% of the sockeye salmon production in the Yentna River drainage (Yanusz et al. 2007). When the fall fry estimates from both lakes are combined, they exhibit a biennial cycle in sockeye salmon production (Figure 5) with the amplitude of the cycle increasing slightly after 2008.

Matching the sockeye salmon abundance cycles, fall fry average sizes have also varied in phase among Chelatna Lake, Judd Lake, and including Larson Lake from 2009 to 2012 (Figure 6). This implies that there is a limitation commonly affecting all 3 lakes over a large geographical distance.

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TABLES AND FIGURES

Table 1.–Target strength (TS) and the mean area backscattering coefficient, sigma (σ), used to echo integrate defined depth strata.

2009	Depth strata integrated	σ	TS
Byers	0 to 10 m	9.56E-06	-50.2
	10 m to 20 m	1.22E-05	-49.1
	20 m to bottom	1.85E-05	-47.3
	whole water column	1.46E-05	-48.3
Chelatna	0 to 40 m	1.27E-05	-49.0
	45 to bottom	1.02E-05	-49.9
	whole water column	1.19E-05	-49.2
Judd	0 to 10 m	4.73E-06	-53.2
	10 m to 30 m	7.21E-06	-51.4
	whole water column	6.49E-06	-51.9
Larson	0 to 5 m	2.39E-06	-56.2
	5 m to 25 m	1.64E-05	-47.8
	25 m to bottom	1.06E-05	-49.8
	whole water column	1.07E-05	-49.7
Stephan	0 to 10 m	1.44E-06	-58.4
	10 m to bottom	1.20E-05	-49.2
	whole water column	5.22E-06	-52.8
Shell	0 to 10 m	2.20E-06	-56.6
	10 m to bottom	3.31E-06	-54.8
	whole water column	2.358E-06	-56.2
Swan	0 to 5 m	3.542E-06	-54.5
	5 m to bottom	3.615E-06	-54.4
	whole water column	3.574E-06	-54.5

2010	Depth strata integrated	σ	TS
Chelatna	0 to 25 m	6.56E-06	-51.8
	25 m to 50 m	1.15E-05	-49.4
	50 m to bottom	5.45E-06	-52.6
	whole water column	7.96E-06	-51.0
Judd	0 to 5 m	2.17E-06	-56.6
	5 to 30 m	3.35E-06	-54.7
	whole water column	3.30E-06	-54.8
Larson	0 to 5 m	2.06E-06	-56.9
	5 m to bottom	1.30E-05	-48.8
	whole water column	9.56E-06	-50.2

-continued-

Table 1.–Page 2 of 3.

	Depth strata integrated	σ	TS
2010			
Shell	0 to 10 m	2.44E-06	-56.1
	10 m to bottom	3.48E-06	-54.6
	whole water column	2.73E-06	-55.6
Fish	0 to 2 m	2.91E-06	-55.4
	2 m to bottom	4.75E-06	-53.2
	whole water column	4.71E-06	-53.3
Trapper	0 to 3 m	3.72E-06	-54.3
	3 m to bottom	7.68E-05	-41.1
	whole water column	7.84E-06	-51.1
Redshirt	0 to 5 m	3.43E-06	-54.7
	5 m to bottom	2.11E-06	-56.8
	whole water column	3.35E-06	-54.8
2011	Depth strata integrated	σ	TS
Caswell	0 to 2 m	1.56E-06	-58.1
	2 m to 8 m	2.54E-06	-55.9
	whole water column	2.32E-06	-56.3
Chelatna	0 to 10 m	1.04E-05	-49.8
	10 m to 25 m	6.35E-06	-52.0
	25 m to 50 m	1.28E-05	-48.9
	whole water column	9.28E-06	-50.3
Judd	0 to 5 m	7.33E-06	-51.4
	5 m to 25 m	4.30E-06	-53.7
	25 m to 35 m	6.43E-06	-51.9
	whole water column	5.17E-06	-52.9
Larson	0 to 25 m	2.95E-06	-55.3
	25 m to 40 m	8.21E-06	-50.9
	whole water column	3.48E-06	-54.6
Shell	0 to 10 m	1.94E-06	-57.1
	10 m to 25 m	4.82E-06	-53.2
	whole water column	2.53E-06	-56.0
Whiskey	0 to 1 m	1.58E-06	-58.0
	1 m to 5 m	2.65E-06	-55.8
	5 m to 8 m	2.25E-06	-56.5
	whole water column	2.57E-06	-55.9

-continued-

Table 1.–Page 3 of 3.

2012	Depth strata integrated	σ	TS
Chelatna	0 to 5 m	1.13E-05	-49.5
	5 m to 20 m	5.29E-06	-52.8
	20 m to 50 m	1.47E-05	-48.3
	whole water column	1.23E-05	-49.1
Judd	0 to 5 m	3.70E-06	-54.3
	5 m to 25 m	3.18E-06	-55.0
	25 m to 30 m	3.40E-06	-54.7
	whole water column	3.27E-06	-54.9
Larson	0 to 5 m	2.10E-06	-56.8
	5 m to 25 m	5.00E-06	-53.0
	25 m to 40 m	4.44E-06	-53.5
	whole water column	4.76E-06	-53.2

Table 2.–Population estimates and densities for all targets and sockeye salmon fry in Susitna River drainage lakes.

	Total estimated targets					Estimation of juvenile sockeye fry						
Lake	Surface	Midwater	Total	SE	Density (n/m^2)	Surface	Midwater	Total	SE	Density (n/m^2)	Age 0	Age 1
2009												
Byers	44,315	192,364	236,679	7.94E+04	0.1589	703	3,053	3,757	1.33E+03	0.0025	3,757	
Chelatna	221,122	1,491,204	1,712,326	1.57E+05	0.1012	212,535	1,433,293	1,645,828	1.52E+05	0.0973	1,645,828	
Judd	39,890	581,025	620,915	1.26E+05	0.4855	31,598	460,250	491,848	9.99E+04	0.3846	429,059	62,789
Larson	1,012,755	3,886,980	4,899,735	8.08E+05	2.0230	392,541	1,506,581	1,899,122	3.13E+05	0.7703	1,899,122	
Shell	1,355,466	4,881,759	6,237,225	1.44E+06	1.0365	1,597	5,753	7,351	1.95E+03	0.0012	7,351	
Stephan	111,413	441,873	553,286	7.85E+04	0.1521	41,264	163,657	204,921	2.91E+04	0.0634	204,921	
Swan	188,430	485,664	674,094	2.10E+05	0.4327	1,427	3,679	5,107	2.81E+03	0.0033	4,938	168
2010												
Chelatna	166,706	1,039,993	1,206,699	2.85E+05	0.0713	149,357	931,758	1,081,115	2.57E+05	0.0639	1,081,115	
Judd	20,784	277,764	298,549	5.17E+04	0.2335	14,624	195,442	210,066	4.76E+04	0.1643	199,618	10,448
Larson	308,688	1,132,696	1,441,384	3.16E+05	0.5951	8,441	30,972	39,413	8.76E+03	0.0163	39,413	
Shell	742,071	2,222,996	2,965,067	1.29E+06	0.4927	0	0	0		0.0000		
Fish	1,686	603,203	604,889	2.75E+05	1.1324	1	451	452	2.10E+02	0.0008	323	129
Trapper[a]	4,806	742,394	747,200	7.05E+05	0.1554	0	0	0		0.0000		
Redshirt[a]	1,225,665	3,275,808	4,501,474	9.91E+05	0.8745	0	0	0		0.0000		
2011												
Chelatna	319,642	1,603,385	1,923,027	2.27E+05	0.1137	308,854	1,549,271	1,858,125	2.20E+05	0.1098	1,858,125	
Judd	68,187	858,104	926,291	1.05E+05	0.7243	48,662	612,391	661,053	7.47E+04	0.5169	436,115	224,938
Larson	126,141	948,125	1,074,266	2.03E+05	0.4435	2,189	16,457	18,646	6.09E+03	0.0077	16,844	1,802
Shell	802,664	2,147,067	2,949,731	8.41E+05	0.4902	0	0	0		0.0000		
Caswell	2,686	1,155,396	1,158,082	2.97E+05	2.1679	0	0	0		0.0000		
Whiskey	18,493	3,820,701	3,839,194	2.48E+06	3.5007	8	1,604	1,612	1.08E+03	0.0015	1,351	261
2012												
Chelatna	253,222	1,199,843	1,453,065	2.61E+05	0.0859	253,222	1,199,843	1,453,065	2.61E+05	0.0859	1,453,065	
Judd	54,245	781,033	835,279	8.70E+04	0.6532	43,144	621,201	664,345	6.93E+04	0.5191	617,384	46,961
Larson	134,891	2,669,425	2,804,316	4.59E+05	1.1579	17,629	348,860	366,489	6.00E+04	0.1513	360,993	5,496

[a] Townet catches consisted of large quantities of the insect, water boatmen (common name), Family *Corixidae.*

Table 3.–Percentage of all species captured in midwater trawl surveys of Susitna River lakes.

Lake	Chinook	Sockeye	Coho	Lake Trout	Whitefish	Stickleback	Sculpin	Other	Total fish	Towing minutes	# Tows
2009											
Byers	0.0	1.6	0.0	0.0	0.0	98.4	0.0	0.0	126	150	5
Chelatna	0.0	96.1	0.0	0.0	2.9	0.0	1.0	0.0	103	330	11
Judd	0.0	79.2	0.0	0.0	0.0	20.8	0.0	0.0	356	151	7
Larson	0.0	38.8	0.0	0.4	0.0	60.9	0.0	0.0	260	195	6
Shell	0.0	0.1	0.0	0.0	0.0	99.9	0.0	0.0	1,697	150	5
Stephan	7.4	37.0	3.7	0.0	0.0	0.0	40.7	11.1	27	237	9
Swan	0.0	0.8	0.01	0.0	0.0	99.2	0.0	0.0	12,012	142	6
2010											
Chelatna	0.0	89.6	0.0	0.0	10.4	0.0	0.0	0.0	221	240	8
Judd	0.0	70.4	0.0	0.0	0.0	29.6	0.0	0.0	469	63	3
Larson	0.0	2.7	0.0	0.0	0.0	97.3	0.0	0.0	1,792	180	6
Shell	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	136	155	5
Fish	0.0	0.1	0.01	0.0	0.0	99.9	0.0	0.0	9,360	70	5
Trapper	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0	75	5
Redshirt	0.0	0.0	0.0	0.0	0.0	0.0	0.0	100.0	0	102	5
2011											
Chelatna	0.0	96.6	0.1	0.0	3.3	0.0	0.0	0.0	800	540	18
Judd	0.0	71.4	0.2	0.0	0.0	28.4	0.0	0.0	454	270	9
Larson	0.0	1.7	0.0	0.0	0.0	98.3	0.0	0.0	4,782	270	9
Shell	0.0	0.0	0.0	0.0	0.0	97.0	3.0	0.0	2,515	180	6
Caswell	0.0	0.0	0.0	0.0	0.0	100.0	0.0	0.0	5,250	90	3
Whiskey	0.0	0.04	0.0	0.0	0.0	99.9	0.0	0.0	50,021	90	3
2012											
Chelatna	0.0	100.0	0.0	0.0	0.0	0.0	0.0	0.0	407	540	18
Judd	0.0	79.5	0.0	0.0	0.0	20.5	0.0	0.0	1,637	270	9
Larson	0.0	13.1	0.0	0.0	0.0	86.9	0.0	0.0	1,033	270	9

Table 4.–Sockeye salmon fry age, mean lengths and mean weights from midwater trawl catches in Susitna River lakes.

	Sockeye Age-0						Sockeye Age-1					
Lake	*N*	%	Length (mm)	SE	Weight (g)	SE	*N*	%	Length (mm)	SE	Weight (g)	SE
2009												
Byers	2	100.0	72.0	1.00	4.4	0.15	0	0.0				
Chelatna	99	100.0	60.6	1.19	2.8	0.15	0	0.0				
Judd	246	87.2	41.2	0.44	0.8	0.03	36	12.8	61.3	0.83	2.3	0.10
Larson	98	100.0	64.2	1.02	3.1	0.14	0	0.0				
Shell	2	100.0	58.0	4.00	2.2	0.55	0	0.0				
Stephan	10	100.0	64.7	5.39	3.7	0.69	0	0.0				
Swan	88	96.7	65.4	0.64	3.1	0.10	3	3.3	84.3	1.86	7.1	0.47
2010												
Chelatna	193	100.0	48.2	0.97	1.7	0.12	0	0.0				
Judd	310	95.1	38.0	0.34	0.7	0.02	16	4.9	60.5	1.15	2.5	0.14
Larson	49	100.0	59.9	2.19	2.9	0.32	0	0.0				
Shell	0						0					
Fish	5	71.4	65.0	1.90	3.36	0.34	2	28.6	81.0	1.00	6.0	0.15
Trapper	0						0					
Redshirt	0						0					
2011												
Chelatna	773	100.0	52.2	0.45	2.0	0.05	0	0.0				
Judd	212	65.9	50.3	0.53	1.4	0.04	110	34.1	66.3	0.38	3.1	0.06
Larson	74	90.2	71.9	1.03	4.4	0.19	8	9.8	87.8	3.48	8.3	0.91
Shell	0						0					
Caswell	0						0					
Whiskey	16	84.2	69.1	1.59	3.9	0.26	3	15.8	75.0	6.03	5.2	1.15
2012												
Chelatna	407	100.0	46.9	0.48	1.3	0.05	0	0.0				
Judd	1,208	92.9	39.0	0.14	0.6	0.01	92	7.1	59.3	0.46	2.2	0.06
Larson	132	98.5	61.7	0.69	2.9	0.10	2	1.5	63.0	3.00	3.0	0.40

Table 5.–Non-salmonid fish mean lengths and mean weights from midwater trawl catches in Susitna River lakes.

	Chinook			Coho			Whitefish			Stickleback			Sculpin		
	N	l (mm)	w (g)	*N*	l (mm)	w (g)	*N*	l (mm)	w (g)	*N*	l (mm)	w (g)	*N*	l (mm)	w (g)
2009															
Byers										119	33.4	0.4			
Chelatna							3	56.3	2.5				1	33.0	0.4
Judd										63	33.0	0.4			
Larson										126	36.3	0.5			
Shell										145	33.0	0.3			
Stephan	2	78.5	6.2	1	98.0	12.5							11	32.8	0.9
Swan				1	65	3.0				263	34.9	0.4			
2010															
Chelatna							23	41.9	1.0						
Judd										100	43.9	0.9			
Larson										152	33.7	0.4			
Shell										118	35.9	0.5			
Fish				1	82	6.7				105	47.0	1.0			
Trapper															
Redshirt															
2011															
Chelatna				1	78	7.0	23	35.7	0.6						
Judd				1	ND[a]	ND				124	45.2	1.1			
Larson										210	30.5	0.3			
Shell										193	41.4	0.8	6	29.8	0.5
Caswell										213	29.7	0.3			
Whiskey										164	33.9	0.5			
2012															
Chelatna															
Judd										127	37.8	0.7			
Larson										153	33.5	0.4			

[a] No data available.

Table 6.–Non-salmonid population estimates from acoustic and midwater trawl surveys of Susitna River lakes.

	Chinook	SE	Coho	SE	Whitefish	SE	Stickleback	SE	Sculpin	SE	Other	SE
2009												
Byers							232,922	7.87E+04				
Chelatna					49,829	2.69E+04			16,610	1.55E+04		
Judd							129,088	5.74E+04				
Larson							3,034,067	6.36E+06				
Shell							6,229,874	1.44E+07				
Stephan	46,107	2.27E+04	23,054	1.60E+04					253,589	5.32E+04		
Swan			56	1.91E+03			668,931	2.09E+05				
2010												
Chelatna					125,584	9.19E+04						
Judd							88,490	2.81E+04				
Larson							1,401,971	3.12E+06				
Shell							2,965,067	1.29E+06				
Fish			67	2.88E+03			604,369	2.75E+05				
Trapper											747,200	7.05E+05
Redshirt											4,501,474	9.91E+05
2011												
Chelatna			2,404	8.04E+03	62,498	4.10E+04						
Judd			2,040	6.93E+03			263,197	5.58E+04				
Larson							1,055,620	2.01E+06				
Shell							2,860,795	8.28E+05	88,937	1.46E+05		
Caswell							1,158,082	2.97E+05				
Whiskey							3,837,582	2.48E+06				
2012												
Chelatna												
Judd							171,444	3.94E+04				
Larson							2,437,828	4.28E+06				

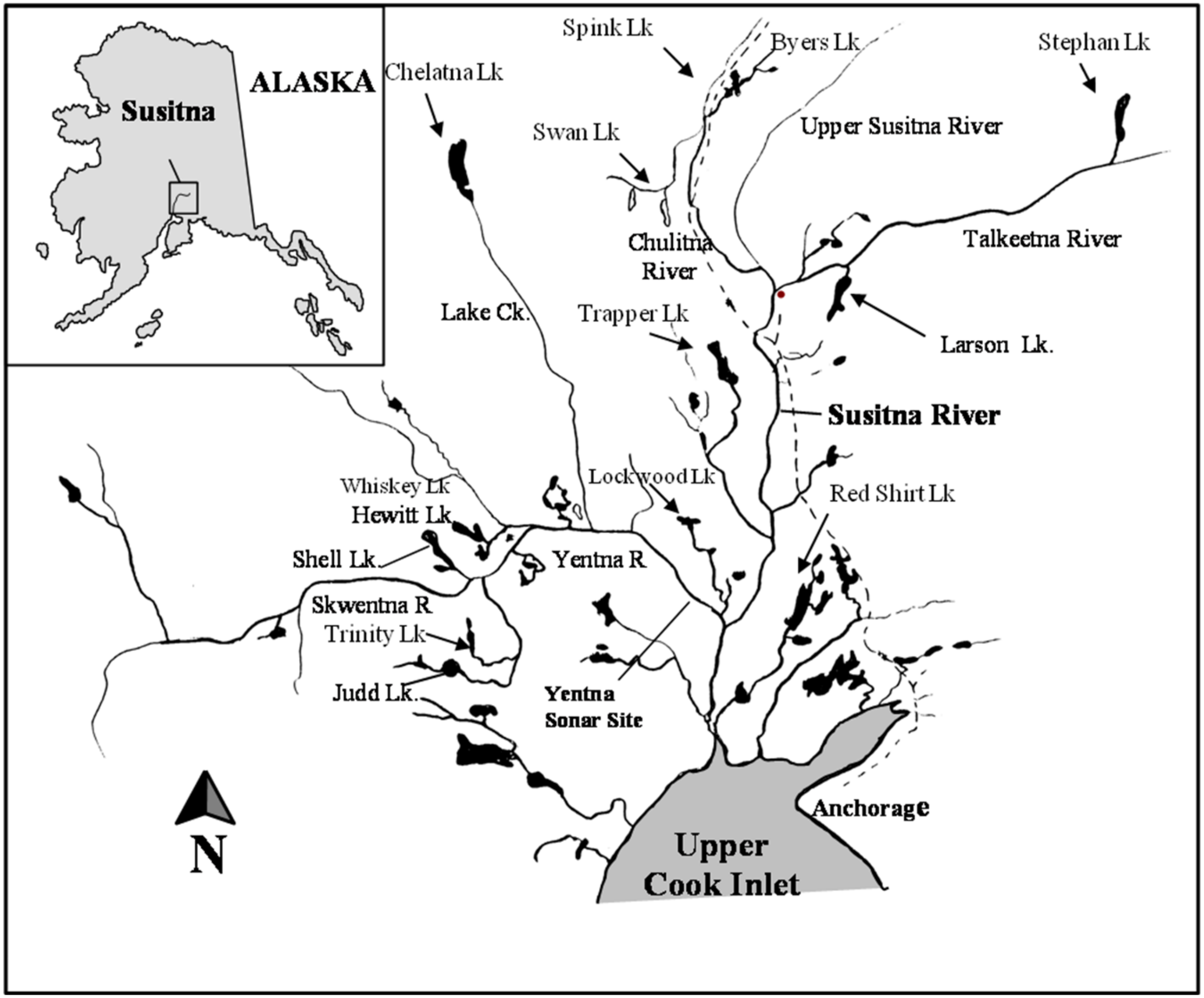

Figure 1.–Susitna River tributaries and drainage lakes.

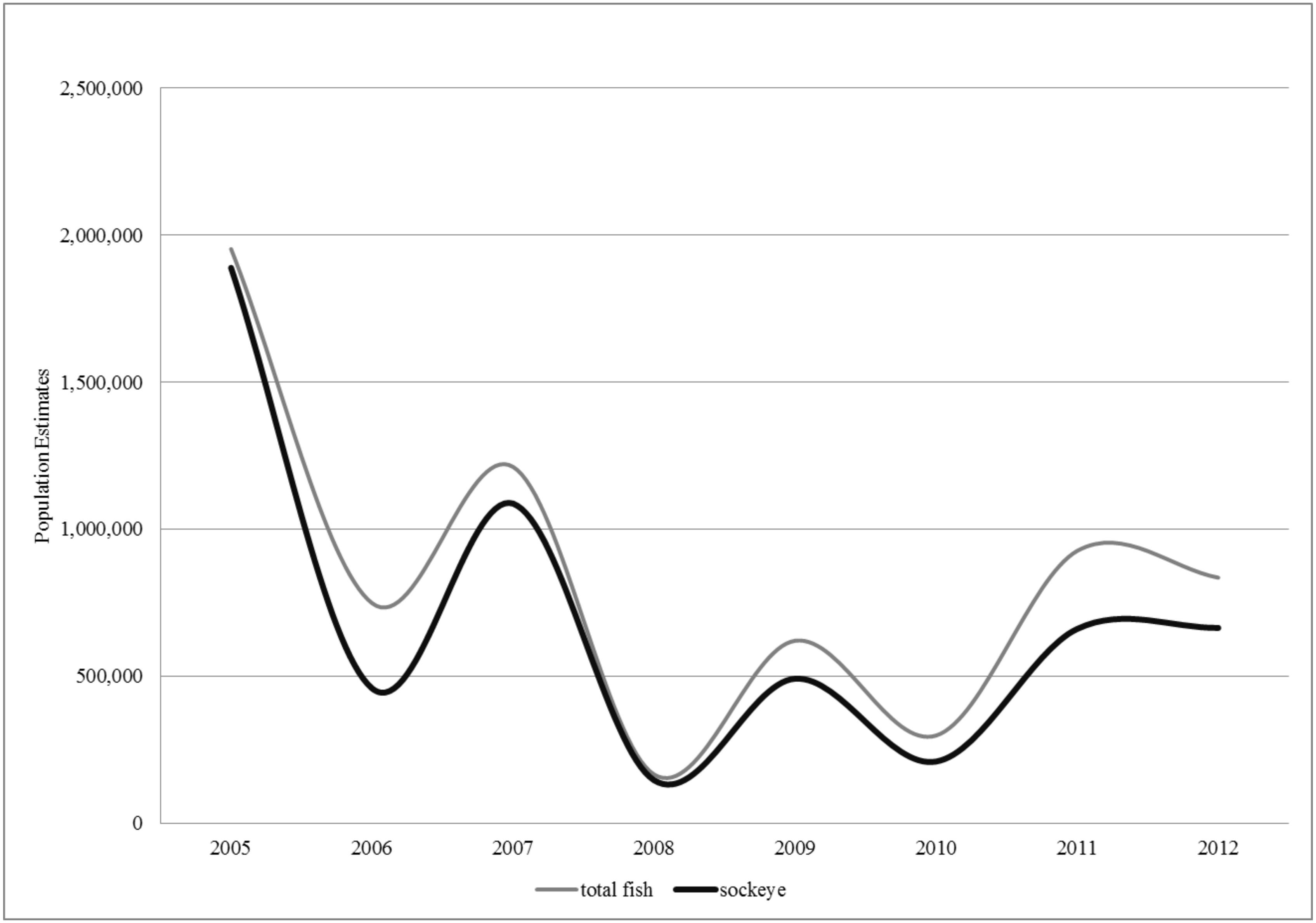

Figure 2.–Judd Lake juvenile sockeye salmon and total fish estimates, 2005 to 2012.

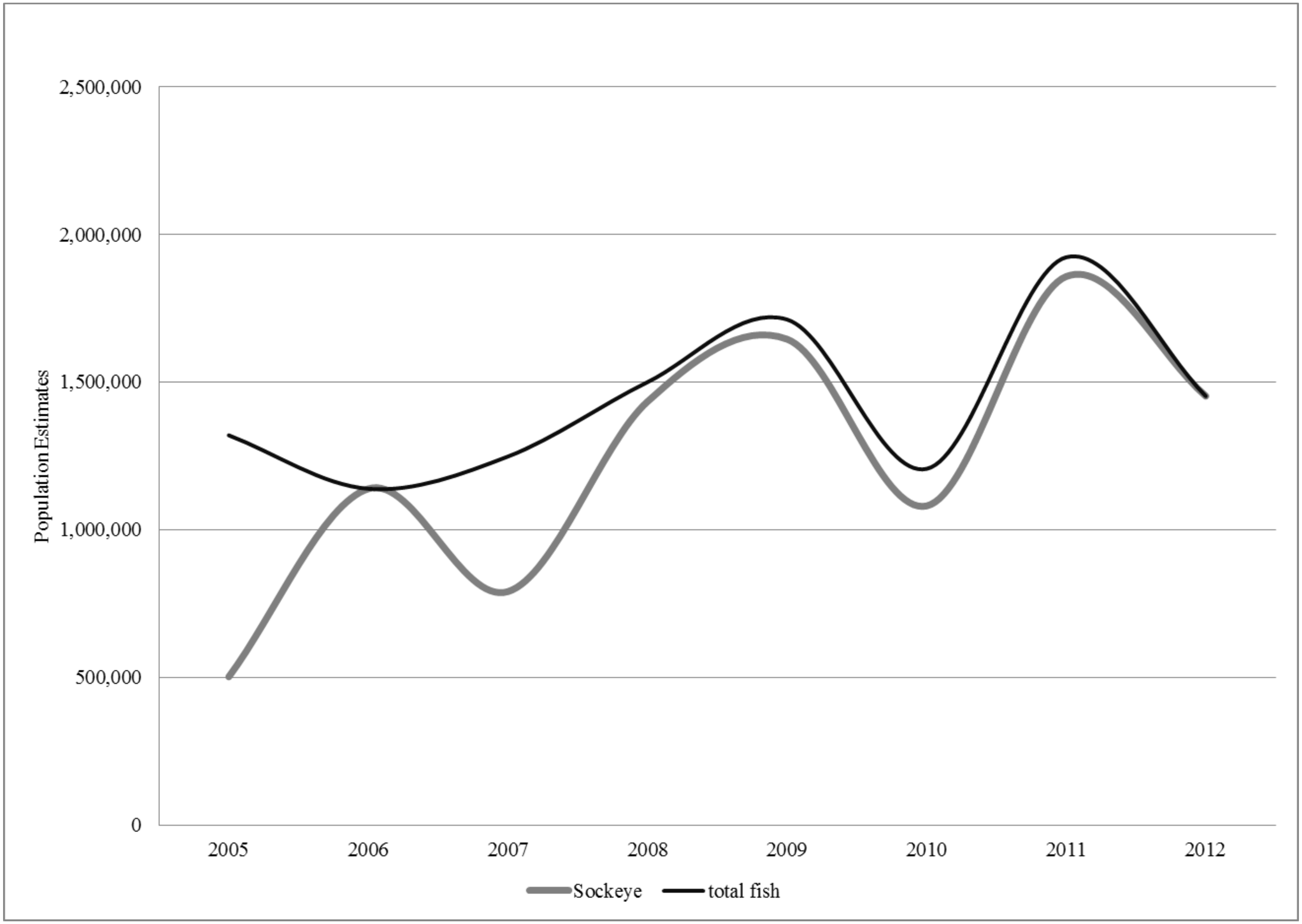

Figure 3.–Chelatna Lake juvenile sockeye salmon and total fish estimates, 2005 to 2012.

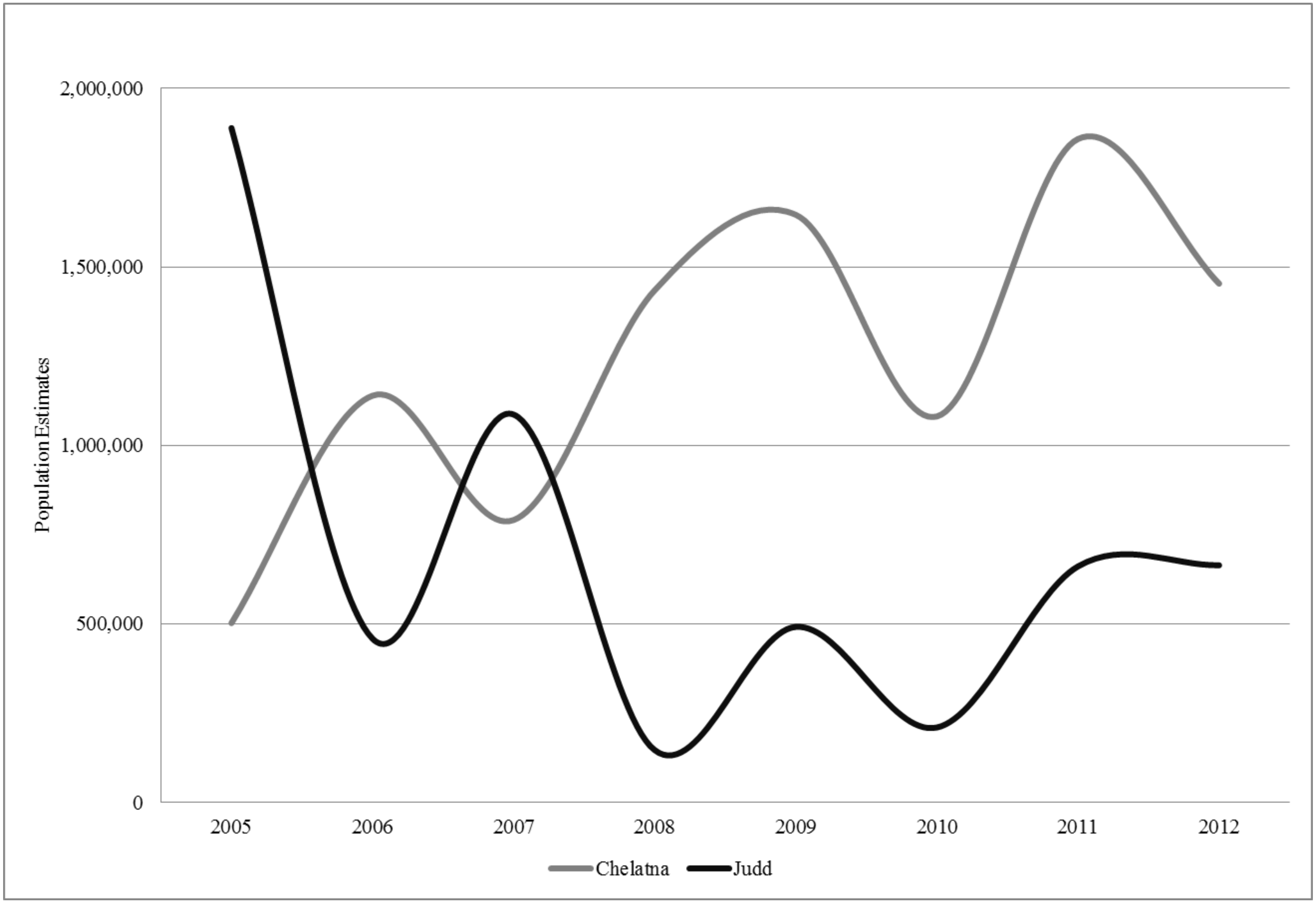

Figure 4.–Chelatna Lake and Judd Lake sockeye salmon estimates, 2005 to 2012.

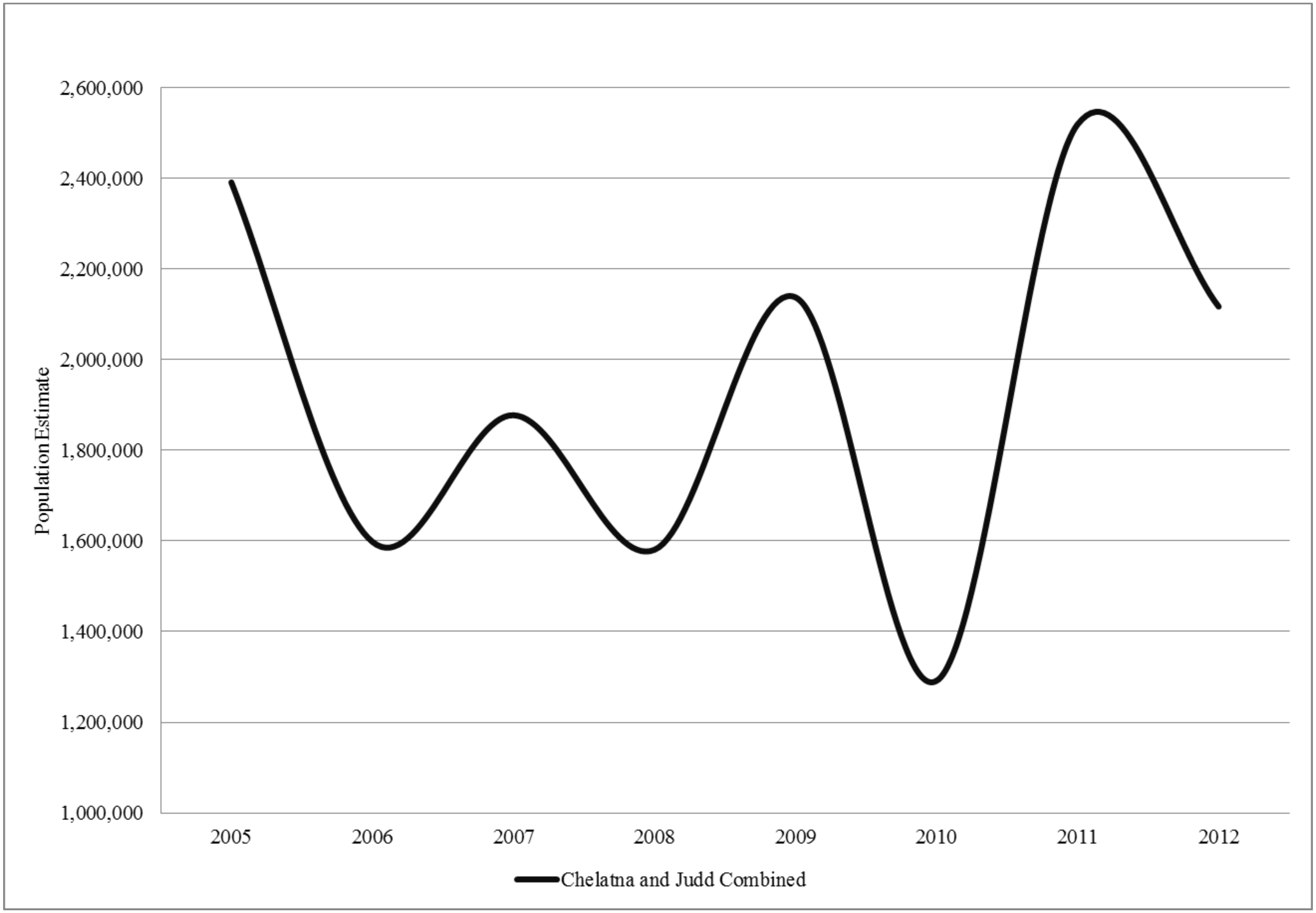

Figure 5.–Chelatna Lake and Judd Lake combined sockeye salmon estimates.

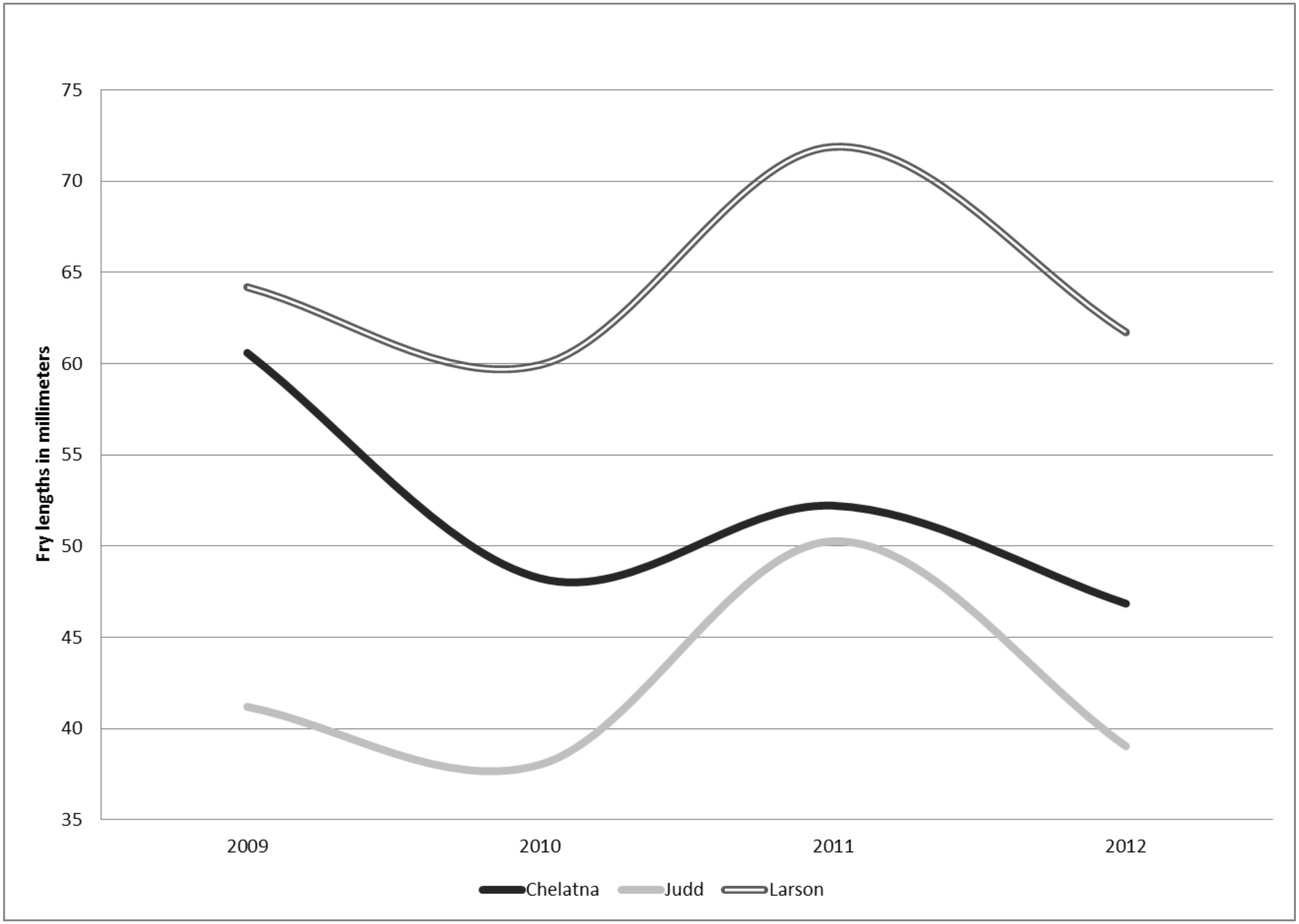

Figure 6.–Sockeye salmon fry age-0 mean lengths (mm) for Chelatna, Judd, and Larson lakes.

APPENDIX A: HYDROACOUSTIC DATA

Appendix A1.–Acoustic survey data collection parameters for lakes in the Susitna River drainage, 2009 to 2012.

Lake	Byers	Caswell	Chelatna	Fish	Judd	Larson	Redshirt	Shell	Stephan	Swan	Trapper	Whiskey
Frequency (kHz)	208	208	208	208	208	208	208	208	208	208	208	208
Beam size (degree)	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6	6.6
Mode	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split	Circular Split
Pulse duration (ms)	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Sample range (m)	1 to 60	1 to 12	1 to 65	1 to 20	1 to 42	1 to 42	1 to 15	1 to 32	1 to 30	1 to 12	1 to 10	1 to 12
Water temperature (C)	12.7	12.4	10.2-12	15	6.4-12.1	9-13.1	14.4	12.5-15	12.8	10	13	11.4
Transducer depth (m)	1	1	1	1	1	1	1	1	1	1	1	1
Threshold (dB)	-65	-65	-65	-65	-65	-65	-65	-65	-65	-65	-65	-65
Ping rate (pps)	4	4	4	4	4	4	4	4	4	4	4	4

Appendix A2.–Chelatna Lake mean sigma (σ) and target strength (TS) for each depth strata.

	2009			2010			2011			2012		
Depth (m)	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS
1	5	8.68E-06	-50.6	1	3.93E-06	-54.1	2	1.23E-05	-49.1	11	9.44E-06	-50.2
2	14	1.65E-05	-47.8	12	1.53E-05	-48.2	21	1.24E-05	-49.1	17	1.34E-05	-48.7
3	34	2.05E-05	-46.9	13	1.39E-05	-48.6	55	7.35E-06	-51.3	41	7.78E-06	-51.1
4	39	1.15E-05	-49.4	22	7.05E-06	-51.5	97	1.05E-05	-49.8	43	1.27E-05	-49.0
5	34	1.77E-05	-47.5	33	7.21E-06	-51.4	124	8.90E-06	-50.5	44	7.02E-06	-51.5
6	44	1.49E-05	-48.3	65	7.15E-06	-51.5	185	8.32E-06	-50.8	40	1.55E-05	-48.1
7	77	9.29E-06	-50.3	85	4.17E-06	-53.8	118	7.09E-06	-51.5	36	1.09E-05	-49.6
8	240	1.02E-05	-49.9	90	4.18E-06	-53.8	128	5.87E-06	-52.3	45	4.97E-06	-53.0
9	359	1.43E-05	-48.4	99	6.14E-06	-52.1	125	6.30E-06	-52.0	35	8.68E-06	-50.6
10	348	1.23E-05	-49.1	88	4.31E-06	-53.7	124	5.90E-06	-52.3	51	8.14E-06	-50.9
11	283	1.14E-05	-49.4	90	5.29E-06	-52.8	166	5.95E-06	-52.3	47	2.96E-06	-55.3
12	234	1.37E-05	-48.6	63	6.83E-06	-51.7	142	3.64E-06	-54.4	58	5.63E-06	-52.5
13	164	1.13E-05	-49.5	83	4.08E-06	-53.9	150	3.71E-06	-54.3	60	5.05E-06	-53.0
14	130	9.84E-06	-50.1	80	5.14E-06	-52.9	112	3.97E-06	-54.0	80	3.19E-06	-55.0
15	141	9.89E-06	-50.0	69	2.68E-06	-55.7	132	5.71E-06	-52.4	72	3.21E-06	-54.9
16	167	1.22E-05	-49.1	113	3.89E-06	-54.1	116	6.72E-06	-51.7	97	3.97E-06	-54.0
17	189	1.23E-05	-49.1	82	7.12E-06	-51.5	106	7.23E-06	-51.4	90	4.69E-06	-53.3
18	155	1.07E-05	-49.7	67	3.49E-06	-54.6	158	8.19E-06	-50.9	91	4.02E-06	-54.0
19	214	1.74E-05	-47.6	54	1.12E-05	-49.5	122	8.73E-06	-50.6	77	4.76E-06	-53.2
20	193	1.07E-05	-49.7	62	7.79E-06	-51.1	105	7.87E-06	-51.0	82	8.41E-06	-50.8
21	208	1.02E-05	-49.9	61	5.81E-06	-52.4	113	9.77E-06	-50.1	88	6.16E-06	-52.1
22	179	1.24E-05	-49.1	45	6.76E-06	-51.7	120	6.46E-06	-51.9	61	6.33E-06	-52.0
23	188	1.14E-05	-49.4	97	1.02E-05	-49.9	107	1.29E-05	-48.9	58	5.79E-06	-52.4
24	160	1.19E-05	-49.2	94	8.05E-06	-50.9	131	8.15E-06	-50.9	66	1.10E-05	-49.6
25	200	1.56E-05	-48.1	59	2.33E-06	-56.3	107	1.12E-05	-49.5	76	1.34E-05	-48.7
26	156	1.43E-05	-48.5	88	1.26E-05	-49.0	109	8.55E-06	-50.7	55	5.34E-06	-52.7
27	174	9.48E-06	-50.2	129	1.12E-05	-49.5	74	1.51E-05	-48.2	64	1.23E-05	-49.1
28	176	1.25E-05	-49.0	98	1.11E-05	-49.5	92	1.09E-05	-49.6	67	1.45E-05	-48.4
29	192	1.22E-05	-49.1	120	1.28E-05	-48.9	72	1.13E-05	-49.5	98	1.03E-05	-49.9

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Appendix A2.–Page 2 of 2.

	2009			2010			2011			2012		
Depth (m)	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS
30	145	1.07E-05	-49.7	63	8.44E-06	-50.7	49	8.54E-06	-50.7	98	1.54E-05	-48.1
31	163	1.77E-05	-47.5	114	1.01E-05	-50.0	68	6.79E-06	-51.7	84	9.19E-06	-50.4
32	123	1.50E-05	-48.2	98	1.56E-05	-48.1	62	1.36E-05	-48.7	118	1.58E-05	-48.0
33	109	1.31E-05	-48.8	130	1.40E-05	-48.5	84	1.32E-05	-48.8	74	1.31E-05	-48.8
34	127	1.25E-05	-49.0	75	9.97E-06	-50.0	84	1.48E-05	-48.3	82	1.40E-05	-48.5
35	58	1.27E-05	-49.0	71	6.43E-06	-51.9	56	1.46E-05	-48.4	47	8.47E-06	-50.7
36	99	2.10E-05	-46.8	51	1.33E-05	-48.8	69	1.14E-05	-49.4	48	1.08E-05	-49.6
37	88	9.33E-06	-50.3	40	1.50E-05	-48.2	86	1.10E-05	-49.6	44	1.63E-05	-47.9
38	70	2.42E-05	-46.2	44	7.88E-06	-51.0	67	1.68E-05	-47.7	40	1.00E-05	-50.0
39	89	7.45E-06	-51.3	42	9.91E-06	-50.0	62	1.29E-05	-48.9	35	1.13E-05	-49.5
40	57	1.58E-05	-48.0	68	1.26E-05	-49.0	45	2.52E-05	-46.0	67	1.56E-05	-48.1
41	51	7.54E-06	-51.2	77	1.25E-05	-49.0	31	1.44E-05	-48.4	73	1.41E-05	-48.5
42	87	1.19E-05	-49.3	85	7.95E-06	-51.0	53	7.18E-06	-51.4	99	1.58E-05	-48.0
43	120	1.99E-05	-47.0	74	1.22E-05	-49.1	58	1.26E-05	-49.0	83	2.29E-05	-46.4
44	155	1.05E-05	-49.8	57	7.71E-06	-51.1	65	9.77E-06	-50.1	77	2.13E-05	-46.7
45	159	1.05E-05	-49.8	49	5.57E-06	-52.5	63	1.03E-05	-49.9	119	2.01E-05	-47.0
46	141	1.24E-05	-49.1	96	1.90E-05	-47.2	65	1.86E-05	-47.3	113	1.81E-05	-47.4
47	112	4.15E-06	-53.8	62	1.64E-05	-47.8	65	1.45E-05	-48.4	124	1.79E-05	-47.5
48	91	7.40E-06	-51.3	57	1.19E-05	-49.2	84	1.25E-05	-49.0	96	1.24E-05	-49.1
49	127	1.32E-05	-48.8	47	8.44E-06	-50.7	85	9.42E-06	-50.3	63	1.73E-05	-47.6
50	135	1.04E-05	-49.8	121	1.21E-05	-49.2	85	1.23E-05	-49.1	103	1.53E-05	-48.2

Appendix A3.–Judd Lake mean sigma and target strength (TS) for each depth strata.

	2009			2010			2011			2012		
Depth (m)	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS
1	9	7.77E-06	-51.1	2	2.24E-06	-56.5	7	6.74E-06	-51.7	3	3.43E-06	-54.6
2	20	3.08E-06	-55.1	6	1.60E-06	-58.0	36	7.44E-06	-51.3	15	3.75E-06	-54.3
3	61	6.18E-06	-52.1	16	1.09E-06	-59.6	54	7.76E-06	-51.1	40	3.15E-06	-55.0
4	165	5.26E-06	-52.8	16	1.39E-06	-58.6	110	5.75E-06	-52.4	68	3.30E-06	-54.8
5	260	4.24E-06	-53.7	30	2.80E-06	-55.5	140	3.93E-06	-54.1	153	2.86E-06	-55.4
6	336	2.97E-06	-55.3	40	3.09E-06	-55.1	189	5.03E-06	-53.0	177	2.79E-06	-55.5
7	449	2.97E-06	-55.3	58	2.83E-06	-55.5	277	4.11E-06	-53.9	244	2.95E-06	-55.3
8	444	3.94E-06	-54.0	70	3.19E-06	-55.0	350	4.07E-06	-53.9	281	2.71E-06	-55.7
9	530	3.96E-06	-54.0	114	4.56E-06	-53.4	447	4.80E-06	-53.2	371	3.02E-06	-55.2
10	642	4.66E-06	-53.3	138	4.97E-06	-53.0	536	3.75E-06	-54.3	448	3.27E-06	-54.8
11	847	6.08E-06	-52.2	149	3.24E-06	-54.9	517	3.94E-06	-54.0	500	3.09E-06	-55.1
12	906	5.84E-06	-52.3	183	4.14E-06	-53.8	645	4.08E-06	-53.9	636	3.13E-06	-55.0
13	1151	6.85E-06	-51.6	194	3.95E-06	-54.0	601	3.83E-06	-54.2	693	3.08E-06	-55.1
14	1045	6.81E-06	-51.7	208	3.54E-06	-54.5	675	4.34E-06	-53.6	859	2.94E-06	-55.3
15	845	8.45E-06	-50.7	240	3.68E-06	-54.3	729	4.41E-06	-53.6	896	3.23E-06	-54.9
16	615	8.04E-06	-50.9	252	3.18E-06	-55.0	855	4.50E-06	-53.5	920	3.31E-06	-54.8
17	465	6.88E-06	-51.6	221	3.62E-06	-54.4	957	4.00E-06	-54.0	946	3.32E-06	-54.8
18	397	7.10E-06	-51.5	200	2.73E-06	-55.6	791	4.06E-06	-53.9	810	3.43E-06	-54.7
19	394	7.46E-06	-51.3	141	2.50E-06	-56.0	660	3.90E-06	-54.1	892	3.66E-06	-54.4
20	317	5.25E-06	-52.8	154	2.76E-06	-55.6	668	4.19E-06	-53.8	919	3.60E-06	-54.4
21	370	6.21E-06	-52.1	176	2.55E-06	-55.9	800	4.18E-06	-53.8	872	2.92E-06	-55.4
22	390	5.72E-06	-52.4	157	3.42E-06	-54.7	952	3.96E-06	-54.0	858	3.86E-06	-54.1
23	495	6.28E-06	-52.0	235	2.51E-06	-56.0	1166	4.91E-06	-53.1	833	3.06E-06	-55.1
24	740	6.62E-06	-51.8	299	3.64E-06	-54.4	936	5.75E-06	-52.4	801	3.66E-06	-54.4
25	890	6.49E-06	-51.9	286	3.16E-06	-55.0	1145	6.31E-06	-52.0	755	2.96E-06	-55.3
26	899	7.25E-06	-51.4	286	3.02E-06	-55.2	1339	6.79E-06	-51.7	662	3.02E-06	-55.2
27	864	7.60E-06	-51.2	318	3.60E-06	-54.4	1371	6.68E-06	-51.8	653	3.31E-06	-54.8
28	737	8.54E-06	-50.7	392	3.12E-06	-55.1	1529	6.36E-06	-52.0	574	3.45E-06	-54.6
29	503	9.36E-06	-50.3	303	3.09E-06	-55.1	1269	6.49E-06	-51.9	518	2.87E-06	-55.4
30	96	8.28E-06	-50.8	14	2.69E-06	-55.7	384	8.89E-06	-50.5	590	3.47E-06	-54.6

Appendix A4.–Larson Lake mean sigma and target strength (TS) for each depth strata.

	2009			2010			2011			2012		
Depth (m)	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS
1	24	1.39E-06	-58.6	11	1.63E-06	-57.9	14	2.09E-06	-56.8	5	2.28E-06	-56.4
2	206	1.93E-06	-57.1	82	1.85E-06	-57.3	36	1.84E-06	-57.4	10	2.12E-06	-56.7
3	713	2.02E-06	-57.0	241	1.89E-06	-57.2	113	1.77E-06	-57.5	67	2.73E-06	-55.6
4	814	2.32E-06	-56.4	305	2.04E-06	-56.9	179	1.67E-06	-57.8	145	1.6E-06	-58.0
5	544	2.37E-06	-56.2	296	2.21E-06	-56.6	237	1.86E-06	-57.3	263	1.96E-06	-57.1
6	466	2.80E-06	-55.5	256	2.25E-06	-56.5	306	2.45E-06	-56.1	405	1.79E-06	-57.5
7	369	3.09E-06	-55.1	144	3.88E-06	-54.1	362	2.33E-06	-56.3	560	2.24E-06	-56.5
8	232	6.21E-06	-52.1	63	3.66E-06	-54.4	369	2.3E-06	-56.4	841	2.57E-06	-55.9
9	209	1.03E-05	-49.9	34	5.46E-06	-52.6	287	3.86E-06	-54.1	973	3.2E-06	-54.9
10	186	1.48E-05	-48.3	51	1.64E-05	-47.8	176	4.81E-06	-53.2	1146	4.37E-06	-53.6
11	202	1.48E-05	-48.3	31	1.13E-05	-49.5	161	6.01E-06	-52.2	1168	5.32E-06	-52.7
12	245	1.76E-05	-47.6	59	1.82E-05	-47.4	114	4.52E-06	-53.5	1094	5.93E-06	-52.3
13	293	1.49E-05	-48.3	25	1.97E-05	-47.1	95	2.24E-06	-56.5	1111	4.85E-06	-53.1
14	297	1.90E-05	-47.2	45	1.17E-05	-49.3	80	3.77E-06	-54.2	1121	5.2E-06	-52.8
15	215	2.23E-05	-46.5	61	1.24E-05	-49.1	77	2.66E-06	-55.7	1115	4.95E-06	-53.1
16	309	1.83E-05	-47.4	60	1.49E-05	-48.3	106	2.68E-06	-55.7	1105	4.44E-06	-53.5
17	272	1.89E-05	-47.2	82	1.53E-05	-48.2	87	2.54E-06	-56.0	1020	4.81E-06	-53.2
18	307	1.76E-05	-47.6	98	1.91E-05	-47.2	67	3.47E-06	-54.6	1096	5.36E-06	-52.7
19	261	2.05E-05	-46.9	115	1.24E-05	-49.1	57	2.69E-06	-55.7	999	4.95E-06	-53.1
20	302	1.98E-05	-47.0	146	1.71E-05	-47.7	63	5.73E-06	-52.4	971	5.2E-06	-52.8
21	261	1.92E-05	-47.2	146	1.39E-05	-48.6	64	4.02E-06	-54.0	972	5.91E-06	-52.3
22	221	1.24E-05	-49.1	151	2.26E-05	-46.5	59	4.45E-06	-53.5	949	4.47E-06	-53.5
23	208	1.83E-05	-47.4	127	1.27E-05	-49.0	40	3.6E-06	-54.4	1005	5.17E-06	-52.9
24	144	1.30E-05	-48.9	91	1.31E-05	-48.8	22	1.13E-05	-49.5	792	5.02E-06	-53.0
25	129	9.77E-06	-50.1	92	1.47E-05	-48.3	25	8.3E-06	-50.8	450	6.59E-06	-51.8
26	120	1.40E-05	-48.5	75	1.23E-05	-49.1	15	5.94E-06	-52.3	375	6.13E-06	-52.1
27	111	1.83E-05	-47.4	145	1.08E-05	-49.7	27	2.29E-06	-56.4	443	5.83E-06	-52.3
28	86	1.81E-05	-47.4	77	5.59E-06	-52.5	20	2.01E-05	-47.0	422	5.98E-06	-52.2
29	76	8.44E-06	-50.7	124	1.14E-05	-49.4	16	6.5E-06	-51.9	367	7.42E-06	-51.3
30	107	9.77E-06	-50.1	88	8.62E-06	-50.6	20	6.66E-06	-51.8	306	4.04E-06	-53.9
31	225	9.82E-06	-50.1	95	1.26E-05	-49.0	28	4.28E-06	-53.7	355	4.98E-06	-53.0
32	149	1.38E-05	-48.6	80	1.28E-05	-48.9	28	1.47E-05	-48.3	311	4.62E-06	-53.4
33	160	9.67E-06	-50.1	119	1.42E-05	-48.5	19	2.24E-05	-46.5	334	4.79E-06	-53.2
34	100	8.08E-06	-50.9	110	8.71E-06	-50.6	24	2.74E-06	-55.6	303	4.54E-06	-53.4
35	174	1.02E-05	-49.9	110	1.36E-05	-48.7	23	3.72E-06	-54.3	373	4.3E-06	-53.7
36	104	8.52E-06	-50.7	12	1.97E-05	-47.1	4	2.47E-06	-56.1	296	4.71E-06	-53.3

Appendix A5.–Shell Lake mean sigma and target strength (TS) for each depth strata.

	2009			2010			2011		
Depth (m)	Targets	σ	TS	Targets	σ	TS	Targets	σ	TS
1	22	1.96E-06	-57.1	54	2.01E-06	-57.0	20	1.49E-06	-58.3
2	201	2.10E-06	-56.8	164	2.03E-06	-56.9	122	1.74E-06	-57.6
3	497	2.09E-06	-56.8	53	1.92E-06	-57.2	155	1.84E-06	-57.3
4	489	1.91E-06	-57.2	21	2.54E-06	-56.0	88	2.23E-06	-56.5
5	493	2.03E-06	-56.9	24	5.56E-06	-52.6	40	2.23E-06	-56.5
6	546	2.09E-06	-56.8	21	2.36E-06	-56.3	43	2.91E-06	-55.4
7	610	2.15E-06	-56.7	15	1.89E-06	-57.2	13	3.08E-06	-55.1
8	671	2.21E-06	-56.5	12	2.35E-06	-56.3	9	3.04E-06	-55.2
9	583	2.39E-06	-56.2	14	2.38E-06	-56.2	11	1.92E-06	-57.2
10	315	2.48E-06	-56.1	5	2.92E-06	-55.3	10	5.59E-06	-52.5
11	155	2.96E-06	-55.3	7	3.41E-06	-54.7	13	2.93E-06	-55.3
12	109	3.02E-06	-55.2	5	1.93E-06	-57.1	6	2.61E-06	-55.8
13	79	2.93E-06	-55.3	2	1.49E-06	-58.3	9	2.64E-06	-55.8
14	59	2.57E-06	-55.9	5	3.21E-06	-54.9	8	4.83E-06	-53.2
15	94	3.74E-06	-54.3	5	1.75E-06	-57.6	11	3.09E-06	-55.1
16	85	3.03E-06	-55.2	9	3.76E-06	-54.2	21	3.41E-06	-54.7
17	126	3.57E-06	-54.5	13	3.75E-06	-54.3	12	2.52E-06	-56.0
18	76	3.83E-06	-54.2	20	4.97E-06	-53.0	9	3.99E-06	-54.0
19	88	3.65E-06	-54.4	26	3.12E-06	-55.1	5	2.00E-06	-57.0
20	84	2.81E-06	-55.5	39	3.63E-06	-54.4	11	1.72E-05	-47.6
21	55	3.34E-06	-54.8	52	2.96E-06	-55.3	5	9.16E-07	-60.4
22	17	3.02E-06	-55.2	11	6.70E-06	-51.7			

Appendix A6.–Byers Lake mean sigma (σ) and target strength (TS) for each depth strata.

2009			
Depth (m)	Targets	σ	TS
1			
2	6	5.73691E-06	-52.4
3	15	2.64462E-05	-45.8
4	12	4.8287E-06	-53.2
5	12	2.89575E-06	-55.4
6	14	8.03569E-06	-50.9
7	24	8.65165E-06	-50.6
8	41	8.8393E-06	-50.5
9	16	1.08791E-05	-49.6
10	17	7.12581E-06	-51.5
11	21	1.0836E-05	-49.7
12	51	9.96294E-06	-50.0
13	71	1.40642E-05	-48.5
14	111	1.31007E-05	-48.8
15	114	1.69597E-05	-47.7
16	143	1.43473E-05	-48.4
17	127	1.26793E-05	-49.0
18	119	1.0331E-05	-49.9
19	155	7.9819E-06	-51.0
20	100	1.06576E-05	-49.7
21	107	1.29856E-05	-48.9
22	105	1.75869E-05	-47.5
23	62	1.70283E-05	-47.7
24	77	1.78041E-05	-47.5
25	75	1.76943E-05	-47.5
26	85	1.92882E-05	-47.1
27	63	1.87484E-05	-47.3
28	53	2.3911E-05	-46.2
29	29	1.74302E-05	-47.6
30	34	2.57451E-05	-45.9
31	31	2.88676E-05	-45.4
32	11	2.55786E-05	-45.9
33	35	2.37897E-05	-46.2
34	14	1.22525E-05	-49.1
35	19	1.4847E-05	-48.3
36	4	3.71499E-05	-44.3
37	8	1.29789E-05	-48.9
38	1	1.16666E-06	-59.3
39	9	1.71635E-05	-47.7
40	5	3.71474E-05	-44.3

Appendix A7.–Caswell Lake mean sigma (σ) and target strength (TS) for each depth strata.

2011			
Depth (m)	Targets	σ	TS
1	34	1.352E-06	-58.7
2	102	1.769E-06	-57.5
3	207	2.203E-06	-56.6
4	397	2.214E-06	-56.5
5	269	2.796E-06	-55.5
6	87	2.55E-06	-55.9
7	7	2.955E-06	-55.3

Appendix A8.–Fish Lake mean sigma (σ) and target strength (TS) for each depth strata.

2010			
Depth (m)	Targets	σ	TS
1	7	2.989E-06	-55.2
2	9	2.854E-06	-55.4
3	51	5.006E-06	-53.0
4	452	4.75E-06	-53.2
5	195	4.697E-06	-53.3
6	2	2.422E-06	-56.2

Appendix A9.–Redshirt Lake mean sigma (σ) and target strength (TS) for each depth strata.

2010			
Depth (m)	Targets	σ	TS
1	43	2.87E-06	-55.4
2	112	3.79E-06	-54.2
3	205	3.43E-06	-54.7
4	275	3.39E-06	-54.7
5	245	3.20E-06	-54.9
6	155	3.20E-06	-54.9
7	50	3.42E-06	-54.7
8	1	2.64E-06	-55.8
9	1	1.58E-06	-58.0

Appendix A10.–Swan Lake mean sigma (σ) and target strength (TS) for each depth strata.

2009			
Depth (m)	Targets	σ	TS
1	15	3.3914E-06	-54.7
2	76	3.5715E-06	-54.5
3	38	3.1107E-06	-55.1
4	13	2.8621E-06	-55.4
5	9	5.6945E-06	-52.4
6	9	4.7546E-06	-53.2

Appendix A11.–Stephan Lake mean sigma (σ) and target strength (TS) for each depth strata.

2009			
Depth (m)	Targets	σ	TS
1	4	1.09219E-06	-59.6
2	9	1.2761E-06	-58.9
3	10	1.9045E-06	-57.2
4	20	1.53614E-06	-58.1
5	17	9.70598E-07	-60.1
6	11	1.20642E-06	-59.2
7	17	9.79095E-07	-60.1
8	15	2.91616E-06	-55.4
9	9	1.90729E-06	-57.2
10	9	8.65089E-07	-60.6
11	7	7.68527E-07	-61.1
12	11	1.24843E-06	-59.0
13	13	9.91011E-07	-60.0
14	2	6.08995E-07	-62.2
15	9	1.13521E-05	-49.4
16	11	2.35477E-05	-46.3
17	9	1.56161E-06	-58.1
18	13	5.09776E-06	-52.9
19	7	8.23056E-06	-50.8
20	9	4.01364E-05	-44.0
21	4	1.30585E-05	-48.8

Appendix A12.–Trapper Lake mean sigma (σ) and target strength (TS) for each depth strata.

2010			
Depth (m)	Targets	σ	TS
1	8	3.90E-06	-54.1
2	5	4.01E-06	-54.0
3	4	3.26E-06	-54.9
4	1	7.68E-05	-41.1

Appendix A13.–Whiskey Lake mean sigma (σ) and target strength (TS) for each depth strata.

2012			
Depth (m)	targets	σ	TS
1	55	1.583E-06	-58.0
2	292	2.213E-06	-56.6
3	477	2.787E-06	-55.5
4	355	2.949E-06	-55.3
5	132	2.105E-06	-56.8
6	27	2.018E-06	-57.0
7	10	2.633E-06	-55.8

Appendix A14.–Poststratified strata used to estimate targets.

2009	Stratum	Transect	Total estimated targets
Byers	1	1	31,170
		2	767
	2	3	15,788
		4	1,528
		5	19,733
		6	2,707
		7	15,636
		8	8,268
	3	9	51,428
		10	10,526
	4	11	57,183
		12	188,824
	5	13	48,025
		14	55,611
		15	64,724
Chelatna	1	1	4,6569
		2	94,887
	2	3	285,719
		4	206,382
		5	120,137
	3	6	171,594
		7	135,672
	4	8	334,014
		9	176,081
	5	10	133,527
		11	249,789
	6	12	147,884
		13	239,348
		14	152,275
	7	15	269,404
		16	277,365
	8	17	378,440
		18	389,480
Judd	1	1	190,882
		2	209,066
		3	128,507
	2	4	405,281
		5	339,830
		6	589,179

-continued-

2009	Stratum	Transect	Total estimated targets
Larson	1	1	1,508,283
		2	834,039
	2	3	506,550
		4	1,012,265
	3	5	583,047
		6	410,102
		7	893,667
	4	8	2,232,311
		9	685,753
		10	1,499,966
	5	11	1,066,639
		12	752,295
		13	783,718
Stephan	1	1	90,762
		2	84,606
	2	3	387,829
		4	291,238
	3	5	182,848
		6	45,111
		7	150,246
Shell	1	1	690,858
		2	245,650
		3	527,035
	2	4	4,360,034
		5	1,788,276
	3	6	411,971
		7	976,992
		8	382,404
	4	9	1,052,149
		10	1,563,069
	5	11	431,291
		12	600,806
		13	167,798
		14	265,522
	6	15	534,635
		16	286,971
Swan	1	1	0
		2	40,163
		3	59,640
	2	4	166,580
		5	240,619
	3	6	507,721
		7	659,243
		8	144,716

-continued-

2010	Stratum	Transect	Total estimated targets
Chelatna	1	1	398,593
		2	6,235
	2	3	162,004
		4	252,578
		5	301,451
	3	6	101,502
		7	92,991
	4	8	23,087
		9	124,778
		10	226,708
	5	11	37,917
		12	22,028
	6	13	103,071
		14	159,032
	7	15	106,896
		16	49,432
	8	17	290,404
		18	318,225
Judd	1	1	47,524
		2	140,074
		3	101,811
	2	4	227,869
		5	194,861
		6	183,506
Larson	1	1	610,562
		2	91,499
		3	89,100
	2	4	116,220
		5	81,427
	3	6	304,335
		7	243,793
		8	247,805
	4	9	182,966
		10	140,670
		11	122,750
	5	12	211,476
		13	250,080
	6	14	250,535
		15	617,376

-continued-

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2010	Stratum	Transect	Total estimated targets
Shell	1	1	281,750
		2	2,182,978
	2	3	1,467,842
		4	478,716
	3	5	169,731
		6	560,602
		7	42,115
		8	827,067
		9	210,373
		10	241,508
		11	678,013
		12	411,876
		13	83,066
		14	114,448
	4	15	797,094
		16	53,995
Fish	1	1	319,929
		2	110,575
	2	3	209,708
		4	69,854
	3	5	101,024
		6	398,689
Trapper	1	1	1,488,408
		2	90,290
		3	662,902
Redshirt	1	1	501,847
		2	815,693
	2	3	357,834
		4	398,532
	3	5	2,584,052
		6	807,437
	4	7	641,504
		8	676,046
	5	9	937,077
		10	1,282,925
2011	**Stratum**	**Transect**	**Total estimated targets**
Caswell	1	1	81,163
		2	473,296
	2	3	387,519
		4	335,980
		5	271,343
	3	6	451,433
		7	626,693
		8	569,587

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2011	Stratum	Transect	Total estimated targets
Chelatna	1	1	167,895
		2	9,727
	2	3	7,000
		4	177,737
		5	56,231
	3	6	159,271
		7	171,598
	4	8	354,037
		9	328,248
	5	10	439,355
		11	961,750
		12	863,484
		13	699,027
		14	886,766
		15	410,380
		16	857,025
	6	17	484,133
		18	548,275
Judd	1	1	73,698
		2	161,536
		3	168,114
		4	258,351
	2	5	391,941
		6	365,667
	3	7	326,264
		8	437,860
Larson	1	1	121,558
		2	129,088
		3	86,429
	2	4	594,409
		5	519,752
		6	475,363
		7	421,206
		8	537,653
		9	561,058
		10	632,558
		11	623,793
	3	12	447,583
		13	190,959
	4	14	60,008
		15	133,815

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2011	Stratum	Transect	Total estimated targets
Shell	1	1	891,229
		2	708,776
		3	398,477
	2	4	956,369
		5	2,428,285
	3	6	267,920
		7	266,919
		8	133,971
		9	286,617
		10	760,060
		11	668,305
		12	194,775
		13	394,347
		14	446,010
	4	15	168,222
		16	254,504
Whiskey	1	1	3,887,732
		2	392,876
	2	3	1,764,756
		4	1,433,113
		5	1,817,982
		6	1,7797,09

2012	Stratum	Transect	Total estimated targets
Chelatna	1	1	37,319
		2	23,395
		3	9,864
	2	4	94,580
		5	90,463
		6	82,322
	3	7	518,781
		8	320,023
	4	9	282,544
		10	111,377
	5	11	134,947
		12	288,831
		13	220,891
	6	14	311,979
		15	428,119
		16	422,946
		17	538,165
		18	844,622

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2012	Stratum	Transect	Total estimated targets
Judd	1	1	301,331
		2	245,423
		3	336,172
	2	4	327,398
		5	260,692
		6	319,852
	3	7	286,636
		8	190,009
Larson	1	1	1,260,533
		2	644,568
	2	3	957,274
		4	868,779
		5	1,195,366
		6	1,032,843
		7	1,449,915
		8	1,000,795
		9	1,324,233
		10	1,251,810
		11	1,298,714
	3	12	690,178
		13	649,372
		14	714,341
		15	739,958

APPENDIX B: CLUSTER AND TWO-STAGE CLUSTER SAMPLING METHODS

Notation

j indexes the tow; *k* indexes the age class; *i* indexes an individual fish

N	= total number of tows in the lake (calculated by volume)
n	= number of tows sampled (assumed random)
m_j	= number of fish in tow j
m	$= \sum_{j=1}^{n} m_j$ = number of fish sampled in the tows
$\bar{m}$	$= \frac{m}{n}$ = average number of fish per sampled tow
M	$= \sum_{j=1}^{N} m_j$ = number of fish in the lake (hydroacoustic estimate)
$\bar{M}$	$= \frac{M}{N}$ = average number of fish per tow for the lake population
o_j	= number of sockeye fry in tow j
o	$= \sum_{j=1}^{n} o_j$ = number of sockeye fry sampled
$\bar{o}$	$= \frac{o}{n}$ = average number of sockeye fry per sampled tow
O	$= \sum_{j=1}^{N} o_j$ = number of sockeye fry in the lake
$\bar{O}$	$= \frac{O}{N}$ = average number of sockeye fry per tow for the lake population
L	= proportion of sockeye fry in the fish population
L_k	= proportion of age-k sockeye fry in the fish population
P_k	= proportion of age-k fry in the sockeye population
l_j	= sample proportion of sockeye fry in tow j
a_j	= number of sockeye fry in tow j sampled for age, weight, and length (AWL)
a_{jk}	= number of age-k sockeye fry sampled for AWL in tow j
l_{jk}	= sample proportion of age-k sockeye fry of the fish in tow j
P_{jk}	= sample proportion of age-k sockeye fry of the sockeye in tow j
Y_j	= total of y in tow j, for all sockeye fry
Y	$= \sum_{j=1}^{N} Y_j$ = total of y, for all sockeye fry
Y_{jk}	= total of y in tow j, for age-k sockeye fry
Y_k	$= \sum_{j=1}^{N} Y_{jk}$ = total of y for age-k sockeye fry
y_{ijk}	= measurement of y (weight or length) on the i^{th} sockeye fry

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A. Whole Fish Population (cluster sampling).

a. The estimate of the proportion of sockeye fry in the fish population is

$$\hat{L} = \frac{\sum_{j=1}^{n} o_j}{\sum_{j=1}^{n} m_j} = \frac{O}{m},$$

with variance estimate

$$v(\hat{L}) = \left(\frac{N-n}{N}\right)\left(\frac{1}{n\overline{\overline{M}}^2}\right)\frac{\sum_{j=1}^{n}(o_j - \hat{L}m_j)^2}{n-1}.$$

b. The estimated proportion of age-k sockeye fry in the fish population is

$$\hat{L}_k = \hat{L}(\hat{P}_k),$$

with variance estimate

$$v(\hat{L}_k) = \hat{L}^2 v(\hat{P}_k) + \hat{P}_k^2 v(\hat{L}) - v(\hat{L})v(\hat{P}_k),$$

where the estimate of P_k and the variance estimate of P_k is given below.

B. Sockeye Salmon Population (2-stage cluster sampling).

a. The estimated proportion of age-k fry in the sockeye population is

$$\hat{P}_k = \frac{\sum_{j=1}^{n} o_j p_{jk}}{\sum_{j=1}^{n} o_j},$$

which is a ratio estimator, where $p_{jk} = \frac{a_{jk}}{a_j}$. The variance estimate is

$$v(\hat{P}_k) = \left(\frac{N-n}{N}\right)\left(\frac{S_r^2}{n\bar{o}^2}\right) + \left(\frac{1}{nN\bar{o}^2}\right)\sum_{j=1}^{n} o_j^2 \left(\frac{o_j - a_j}{o_j}\right)\left[\frac{p_{jk}(1-p_{jk})}{a_j - 1}\right],$$

where $S_{kr}^2 = \frac{\sum_{j=1}^{n} o_j^2 \left(p_{jk} - \hat{P}_k\right)^2}{n-1}$.

C. Sockeye Fry Abundance Estimates.

a. Estimated total sockeye fry abundance is

$$\hat{O} = \hat{L}(\hat{M}),$$

with variance estimate

-continued-

$$v(\hat{O}) = \hat{L}^2 v(\hat{M}) + \hat{M}^2 v(\hat{L}) - v(\hat{L}) v(\hat{M}),$$

where $\hat{M}$ is the total fish population estimate (obtained hydroacoustically).

b. Estimated age-*k* sockeye fry abundance is

$$\hat{O}_k = \hat{L}_k(\hat{M}),$$

with variance estimate

$$v(\hat{O}_k) = \hat{L}_k^2 v(\hat{M}) + \hat{M}^2 v(\hat{L}_k) - v(\hat{L}_k) v(\hat{M}).$$

D. Sockeye Fry W-L Estimates (2-stage cluster sampling).

a. The estimated average weight or length for the whole fry population is

$$\hat{\bar{Y}} = \frac{\sum_{j=1}^{n} o_j \bar{y}_j}{\sum_{j=1}^{n} o_j},$$

which is a ratio estimator, where $\bar{y}_j = \frac{\sum_{j=1}^{a_j} y_{ij}}{a_j}$. The variance estimate is

$$v(\hat{\bar{Y}}) = \left(\frac{N-n}{N}\right)\left(\frac{S_r^2}{n\bar{o}^2}\right) + \left(\frac{1}{nN\bar{o}}\right)\sum_{j=1}^{n} o_j^2 \left(\frac{o_j - a_j}{o_j}\right)\left(\frac{S_j^2}{o_j}\right),$$

where $S_r^2 = \frac{\sum_{j=1}^{n} o_j^2 (\bar{y}_j - \hat{\bar{Y}})^2}{n-1}$ and $S_j^2 = \frac{\sum_{j=1}^{a_j} (y_{ij} - \bar{y}_j)^2}{a_j - 1}$.

b. The estimated average weight or length of age-*k* sockeye fry is

$$\bar{Y}_k = \frac{\sum_{j=1}^{n} o_{jk} \bar{y}_{jk}}{\sum_{j=1}^{n} o_{jk}},$$

which is a subpopulation ratio estimator, where $o_{jk} = o_j(p_{jk})$ and $\bar{y}_{jk} = \frac{\sum_{j=1}^{a_{jk}} y_{ij}}{a_{jk}}$.

An approximate variance estimate is

$$v(\bar{Y}_k) \approx \left(\frac{N-n}{N}\right)\left(\frac{S_{kr}^2}{n\bar{o}_k^2}\right) + \left(\frac{1}{nN\bar{o}_k}\right)\sum_{j=1}^{n} o_{jk}^2 \left(\frac{o_j - a_j}{o_j}\right)\left(\frac{S_{jk}^2}{o_{jk}}\right),$$

where $S_{kr}^2 = \frac{\sum_{j=1}^{n} o_{jk}^2 (\bar{y}_{jk} - \hat{\bar{Y}}_k)^2}{n-1}$ and $S_{jk}^2 = \frac{\sum_{j=1}^{a_{jk}} (y_{ijk} - \bar{Y}_{jk})}{a_{jk} - 1}$.

APPENDIX C: HISTORICAL FISH ABUNDANCE AND SOCKEYE SALMON FRY SIZE ESTIMATES

Appendix C1.–Historical sockeye salmon fry age, mean lengths, and mean weights from midwater trawls in Chelatna Lake.

	Sockeye Age-0						Sockeye Age-1					
Chelatna	*N*	%	Length (mm)	SE	Weight (g)	SE	*N*	%	Length (mm)	SE	Weight (g)	SE
1993	65	98.5	62.0		3.3		1	1.5	73.0		4.9	
1994	116	100.0	56.0		2.6		0					
1995	12	100.0	56.0		2.4		0					
2005	59	100.0	57.5	1.74	2.7	0.23	0					
2006	19	100.0	50.8	1.92	1.7	0.17	0					
2007	82	98.8	68.1	1.43	4.0	0.23	1	1.2	82.0		6.5	
2008	109	100.0	45.6	1.01	1.3	0.12	0					
2009	99	100.0	60.6	1.19	2.8	0.15	0					
2010	193	100.0	48.2	0.97	1.7	0.12	0					
2011	773	100.0	52.2	0.45	2.0	0.05	0					
2012	407	100.0	46.9	0.48	1.3	0.05	0					

Appendix C2.–Historical sockeye salmon fry age, mean lengths, and mean weights from midwater trawls in Judd Lake.

	Sockeye Age-0						Sockeye Age-1					
Judd	*N*	%	Length (mm)	SE	Weight (g)	SE	*N*	%	Length (mm)	SE	Weight (g)	SE
1993	329	91.9	46.0		1.2		29	8.1	64.0		3.1	
1994	290	97.6	39.0		0.8		7	2.4	62.0		3.1	
1995[a]	282	94.0	38.0		0.6		18	6.0	57.0		2.0	
1995[b]	283	94.3	37.0		0.6		17	5.7	58.0		2.2	
2005	554	89.8	43.8	0.28	1.0	0.02	63	10.2	61.5	0.47	2.5	0.05
2006	105	58.7	53.8	0.50	2.1	0.05	74	41.3	66.0	0.68	3.7	0.07
2007	104	100.0	47.6	1.01	1.3	0.07	0					
2008	308	97.8	37.6	0.27	0.7	0.02	7	2.2	64.6	2.26	3.2	0.33
2009	246	87.2	41.2	0.44	0.8	0.03	36	12.8	61.3	0.83	2.3	0.10
2010	310	95.1	38.0	0.34	0.7	0.02	16	4.9	60.5	1.15	2.5	0.14
2011	212	65.8	50.3	0.53	1.4	0.04	110	34.2	66.3	0.38	3.1	0.06
2012	1,208	92.9	39.0	0.14	0.6	0.01	92	7.1	59.3	0.46	2.2	0.06

[a] Small trawl net.

[b] Large trawl net.

Appendix C3.–Historical sockeye salmon fry age, mean lengths, and mean weights from midwater trawls in Larson Lake.

	Sockeye Age-0						Sockeye Age-1					
Larson	*N*	%	Length (mm)	SE	Weight (g)	SE	*N*	%	Length (mm)	SE	Weight (g)	SE
1993	249	98.0	55.0		2.1		5	2.0	68.0		4.0	
1994	165	100.0	54.0		2.1		0					
2005	95	100.0	58.9	0.85	2.5	0.10	0					
2006	8	100.0	62.4	2.78	2.9	0.40	0					
2007	8	100.0	61.5	5.57	3.0	0.73	0					
2009	98	100.0	64.2	1.02	3.1	0.14	0					
2010	49	100.0	59.9	2.19	2.9	0.32	0					
2011	74	90.2	71.9	1.03	4.4	0.19	8	9.8	87.8	3.48	8.3	0.91
2012	132	98.5	61.7	0.69	2.9	0.10	2	1.5	63.0	3.00	3.0	0.40

Appendix C4.–Historical sockeye salmon fry age, mean lengths, and mean weights from midwater trawls in Shell Lake.

	Sockeye Age-0						Sockeye Age-1					
Shell	*N*	%	Length (mm)	SE	Weight (g)	SE	*N*	%	Length (mm)	SE	Weight (g)	SE
1993	13	100.0	63.0		3.3		0					
1994	36	100.0	55.0		2.8		0					
2005	12	100.0	66.7	1.83	3.5	0.26	0					
2006	7	100.0	73.7	3.88	5.2	0.91	0					
2007	0						0					
2009	2	100.0	58.0	4.00	2.2	0.55	0					
2010	0						0					
2011	0						0					

Appendix C5.–Historical population estimates and densities for all targets and sockeye salmon fry in Chelatna Lake.

	Total estimated targets					Estimation of juvenile sockeye fry						
Chelatna	Surface	Midwater	Total	SE	Density (n/m2)	Surface	Midwater	Total	SE	Density (n/m2)	Age 0	Age 1
1993			1,427,000					1,293,813				
1994			2,946,252					2,825,504				
1995			3,571,547					3,571,547				
2005	72,428	1,247,698	1,320,126	1.50E+05	0.0835	27,569	474,930	502,499	6.59E+04	0.0317	502,499	
2006	129,926	1,009,278	1,139,204	4.06E+05	0.0727	129,926	1,009,278	1,139,204	4.57E+05	0.0727	1,139,204	
2007	35,150	1,213,279	1,248,429	2.10E+05	0.0790	22,271	768,719	790,990	1.11E+05	0.0500	781,419	9,492
2008	93,425	1,406,957	1,500,382	4.13E+05	0.0949	89,314	1,345,051	1,434,365	3.54E+05	0.0906	1,434,365	
2009	221,122	1,491,204	1,712,326	1.57E+05	0.1012	212,535	1,433,293	1,645,828	1.52E+05	0.0973	1,645,828	
2010	166,706	1,039,993	1,206,699	2.85E+05	0.0713	149,357	931,758	1,081,115	2.57E+05	0.0639	1,081,115	
2011	319,642	1,603,385	1,923,027	2.27E+05	0.1137	308,854	1,549,271	1,858,125	2.20E+05	0.1098	1,858,125	
2012	253,222	1,199,843	1,453,065	2.61E+05	0.0859	253,222	1,199,843	1,453,065	2.61E+05	0.0859	1,453,065	

Appendix C6.–Historical population estimates and densities for all targets and sockeye salmon fry in Judd Lake.

	Total estimated targets					Estimation of juvenile sockeye fry						
Judd	Surface	Midwater	Total	SE	Density (n/m2)	Surface	Midwater	Total	SE	Density (n/m2)	Age 0	Age 1
1993			343,378					277,865				
1994			1,148,060					1,036,661				
1995			271,729					267,014				
2005	220,378	1,732,711	1,953,089	5.26E+05	1.5273	213,124	1,675,678	1,888,802	4.16E+05	1.4770	1,698,033	196,435
2006	83,047	665,602	748,650	2.60E+05	0.5854	50,909	408,023	458,933	7.52E+04	0.3589	269,210	189,723
2007	67,907	1,144,109	1,212,016	2.78E+05	0.9478	60,882	1,025,753	1,086,635	2.39E+05	0.8498	1,086,635	
2008	13,509	152,529	166,038	4.27E+04	0.1298	11,915	134,531	146,210	3.33E+04	0.1145	143,195	3,251
2009	39,890	581,025	620,915	1.26E+05	0.4855	31,598	460,250	491,848	9.99E+04	0.3846	429,059	62,789
2010	20,784	277,764	298,549	5.17E+04	0.2335	14,624	195,442	210,066	4.76E+04	0.1643	199,618	10,448
2011	68,187	858,104	926,291	1.05E+05	0.7243	48,662	612,391	661,053	7.47E+04	0.5169	436,115	224,938
2012	54,245	781,033	835,279	8.70E+04	0.6532	43,144	621,201	664,345	6.93E+04	0.5191	617,384	46,961

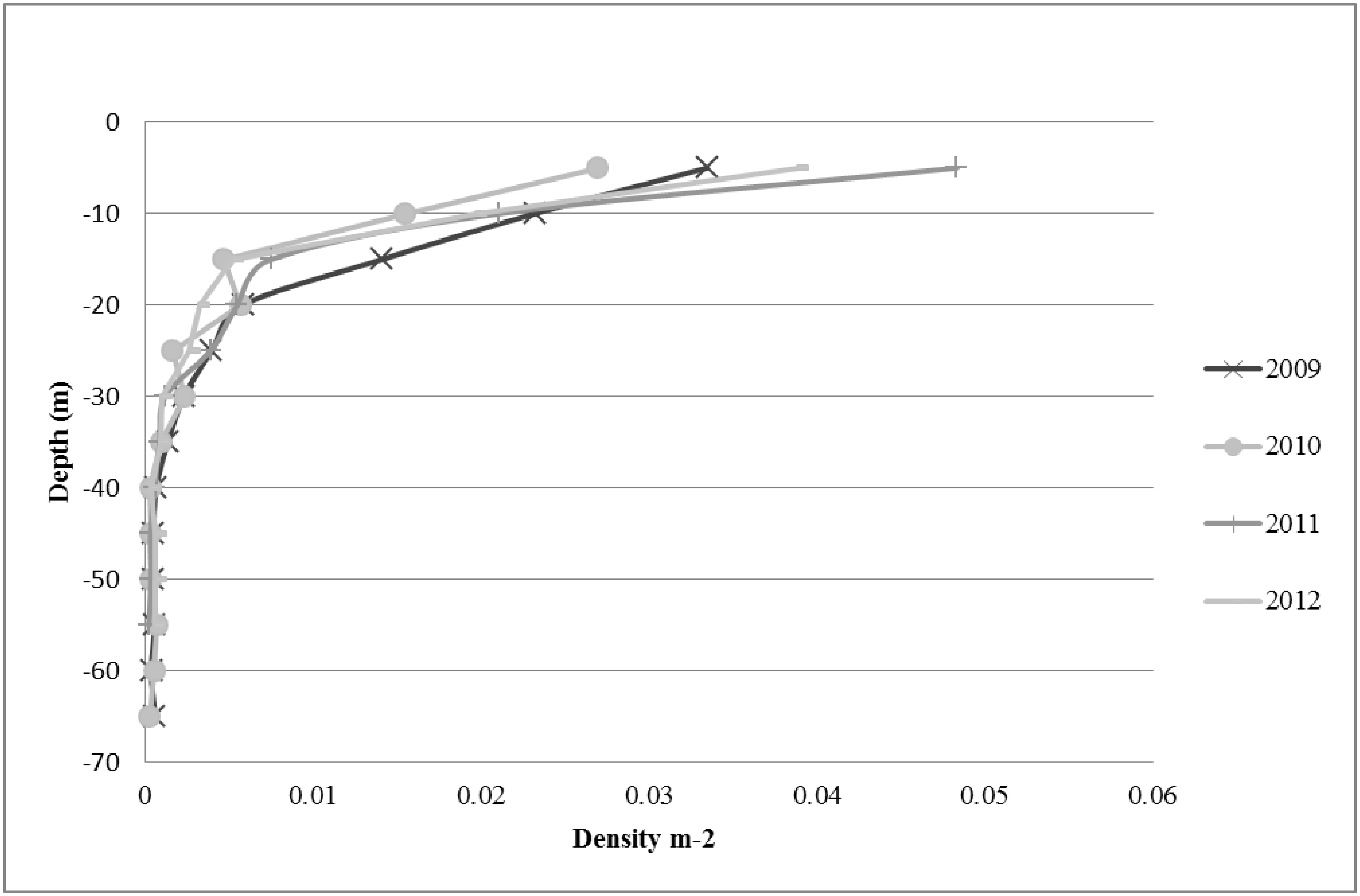
Appendix C7.–Historical population estimates and densities for all targets and sockeye salmon fry in Larson Lake.

	Total estimated targets					Estimation of juvenile sockeye fry						
Larson	Surface	Midwater	Total	SE	Density (n/m2)	Surface	Midwater	Total	SE	Density (n/m2)	Age 0	Age 1
1985			379,000					254,000				
1986			292,000					128,000				
1987			1,024,000					174,000				
1993			269,064					9,737				
1994			532,837					520,270				
2005	52,388	2,073,772	2,126,160	3.51E+05	1.2023	4,832	191,270	196,102	4.31E+04	0.1108	196,102	
2006	101,690	963,050	1,064,740	1.66E+05	0.6021	3,968	37,582	41,551	4.59E+04	0.0235	41,551	
2007	597,338	2,079,731	2,677,069	6.93E+05	1.5138	5,369	18,694	24,064	6.90E+04	0.1362	15,040	
2009	1,012,755	3,886,980	4,899,735	8.08E+05	2.0230	392,541	1,506,581	1,899,122	3.13E+05	0.7703	1,899,122	
2010	308,688	1,132,696	1,441,384	3.16E+05	0.5951	8,441	30,972	39,413	8.76E+05	0.0163	39,413	
2011	126,141	948,125	1,074,266	2.03E+05	0.4435	2,189	16,457	18,646	6.09E+03	0.0077	16,844	1,802
2012	134,891	2,669,425	2,804,316	4.59E+05	1.1579	17,629	348,860	366,489	6.00E+04	0.1513	360,993	5,496

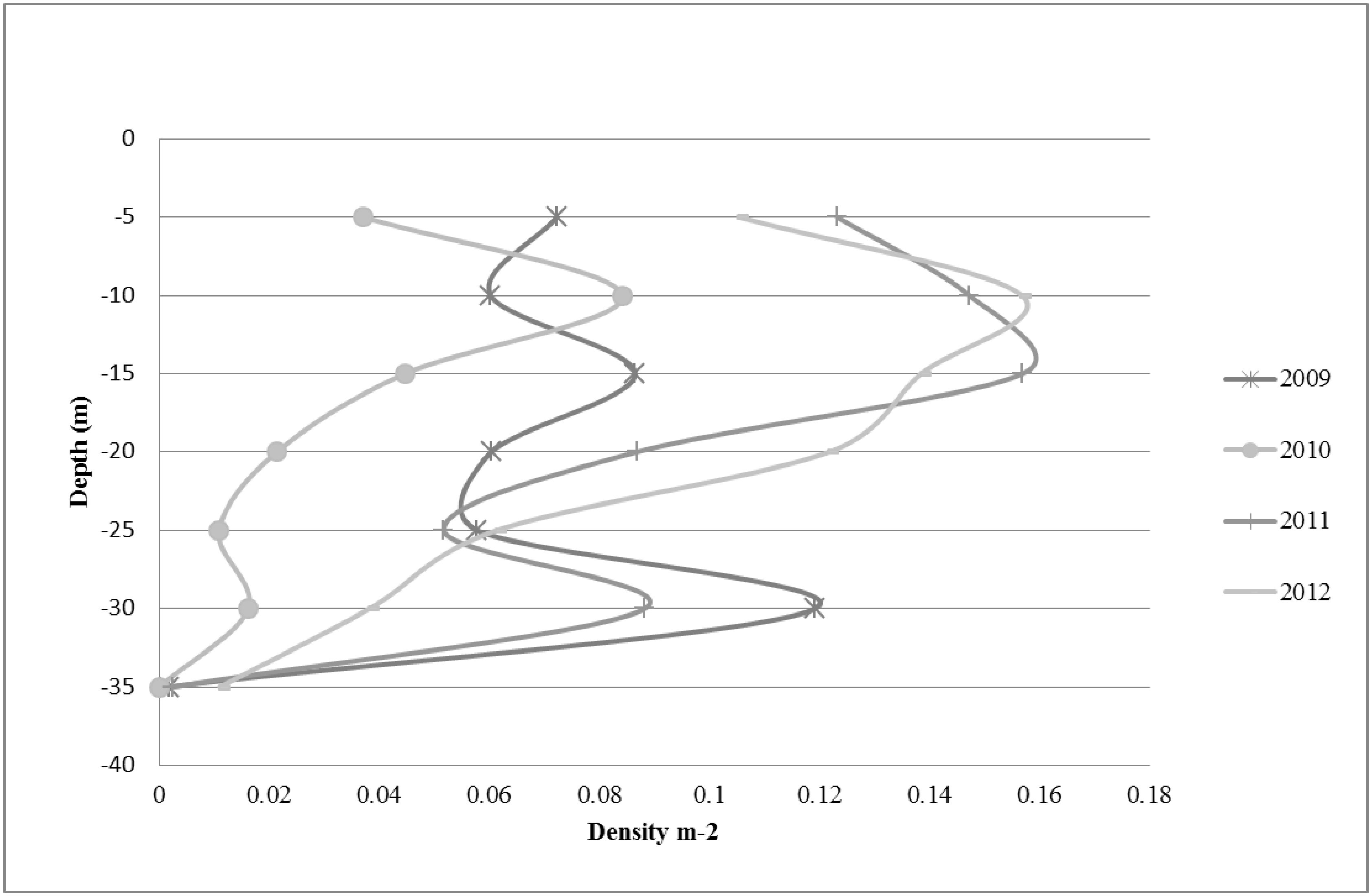
Appendix C8.–Historical population estimates and densities for all targets and sockeye salmon fry in Shell Lake.

	Total estimated targets					Estimation of juvenile sockeye fry						
Shell	Surface	Midwater	Total	SE	Density (n/m2)	Surface	Midwater	Total	SE	Density (n/m2)	Age 0	Age 1
1985			1,038,000					208,000				
1986			1,497,000					254,000				
1993			1,354,520					19,843				
1994			2,168,964					367,469				
2005	224,911	1,743,356	1,968,267	2.46E+05	0.3762	6,615	51,275	57,890	3.57E+04	0.0111	57,890	
2006	182,261	1,279,292	1,461,553	1.53E+05	0.2793	1,844	12,941	14,784	3.34E+04	0.0028	14,784	
2007	722,140	2,498,857	3,220,998	1.08E+06	0.6156	0	0	0				
2009	1,355,466	4,881,759	6,237,225	1.44E+06	1.0365	1,597	5,753	7,351	1.95E+03	0.0012	7,351	
2010	742,071	2,222,996	2,965,067	1.29E+06	0.4927	0	0	0				
2011	802,664	2,147,067	2,949,731	8.41E+05	0.4902	0	0	0				

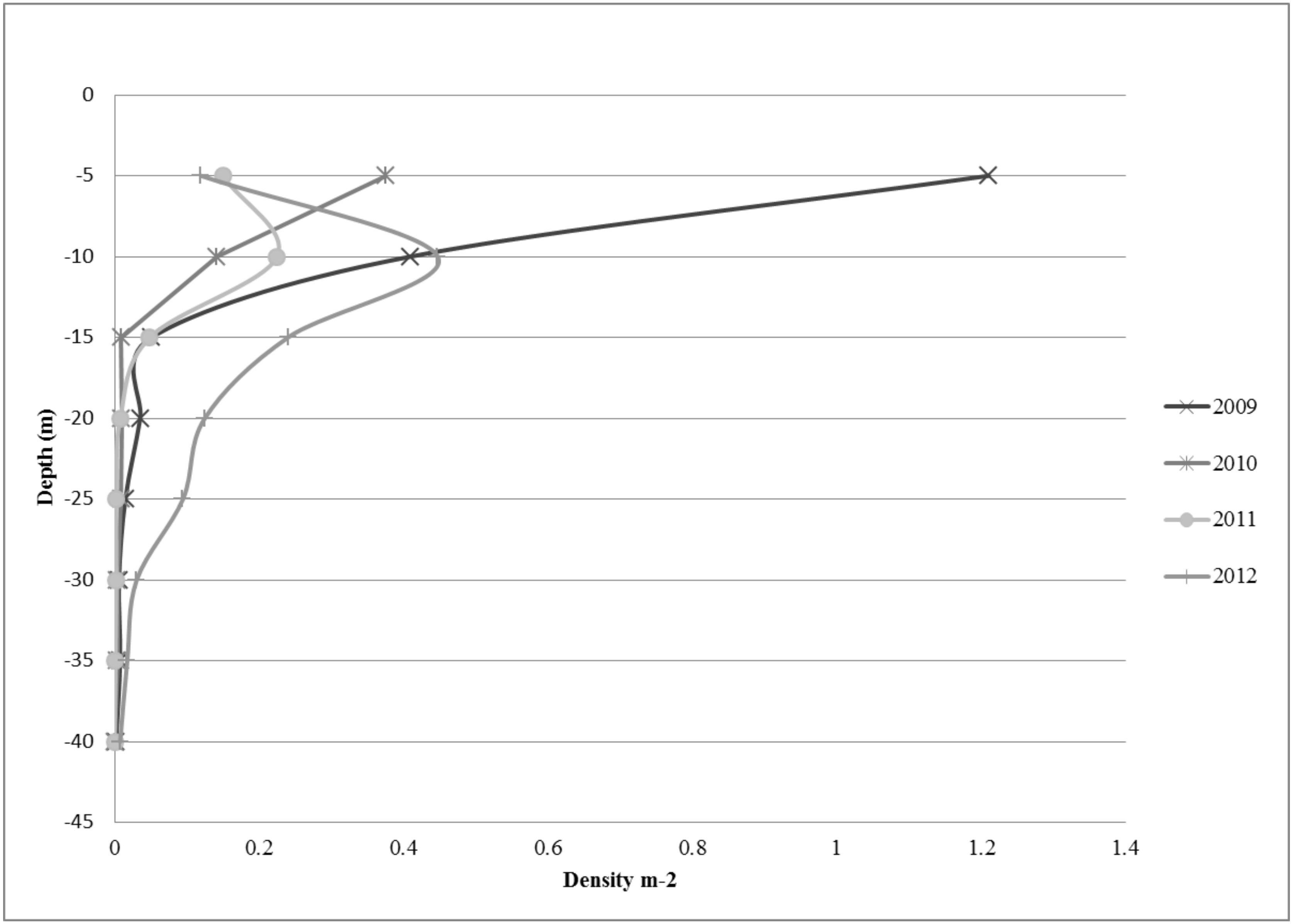
APPENDIX D: FISH DENSITIES



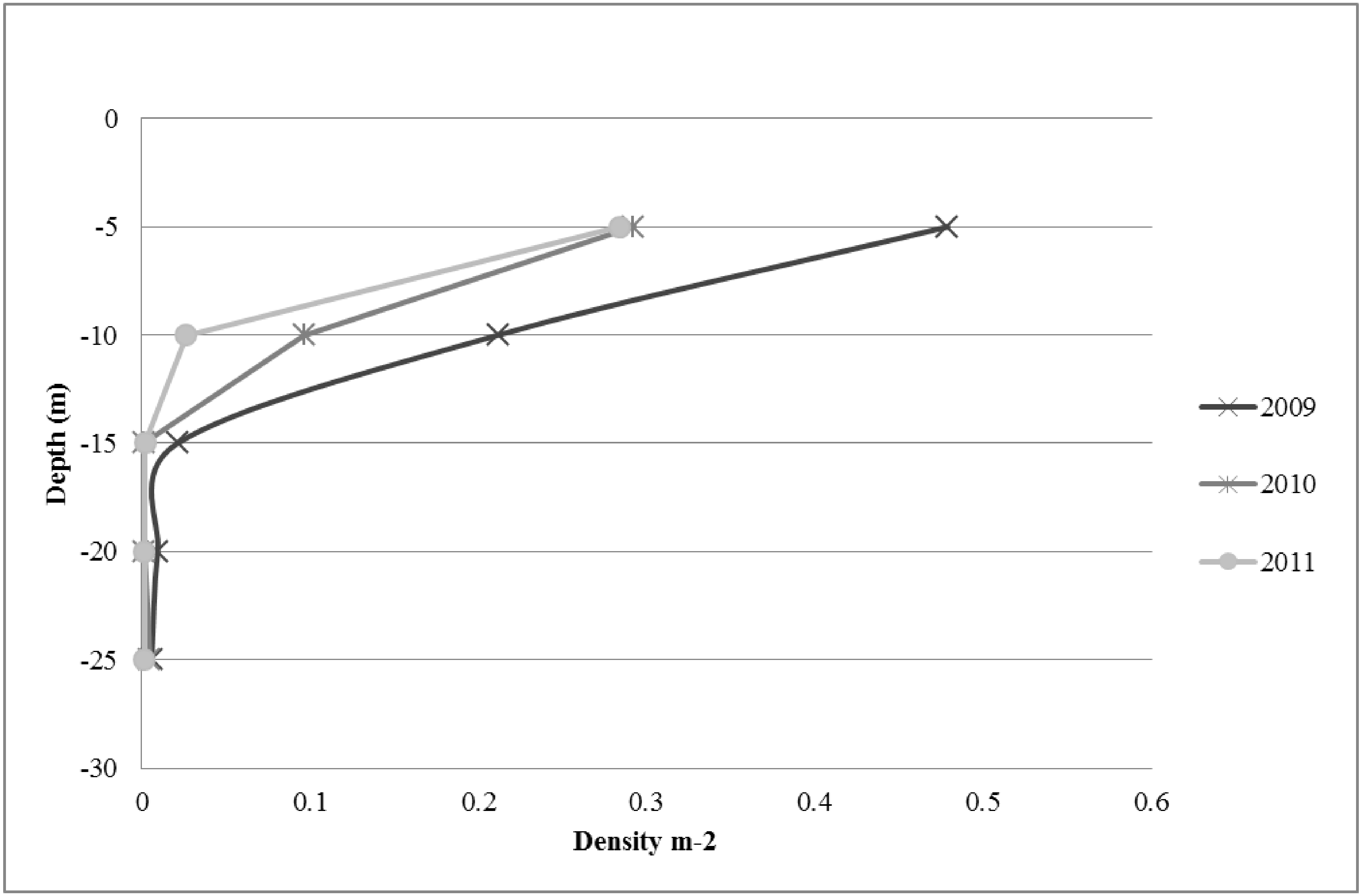
Appendix D1.–Historical fish densities for Chelatna Lake by depth.



Appendix D2.–Historical fish densities for Judd Lake by depth.



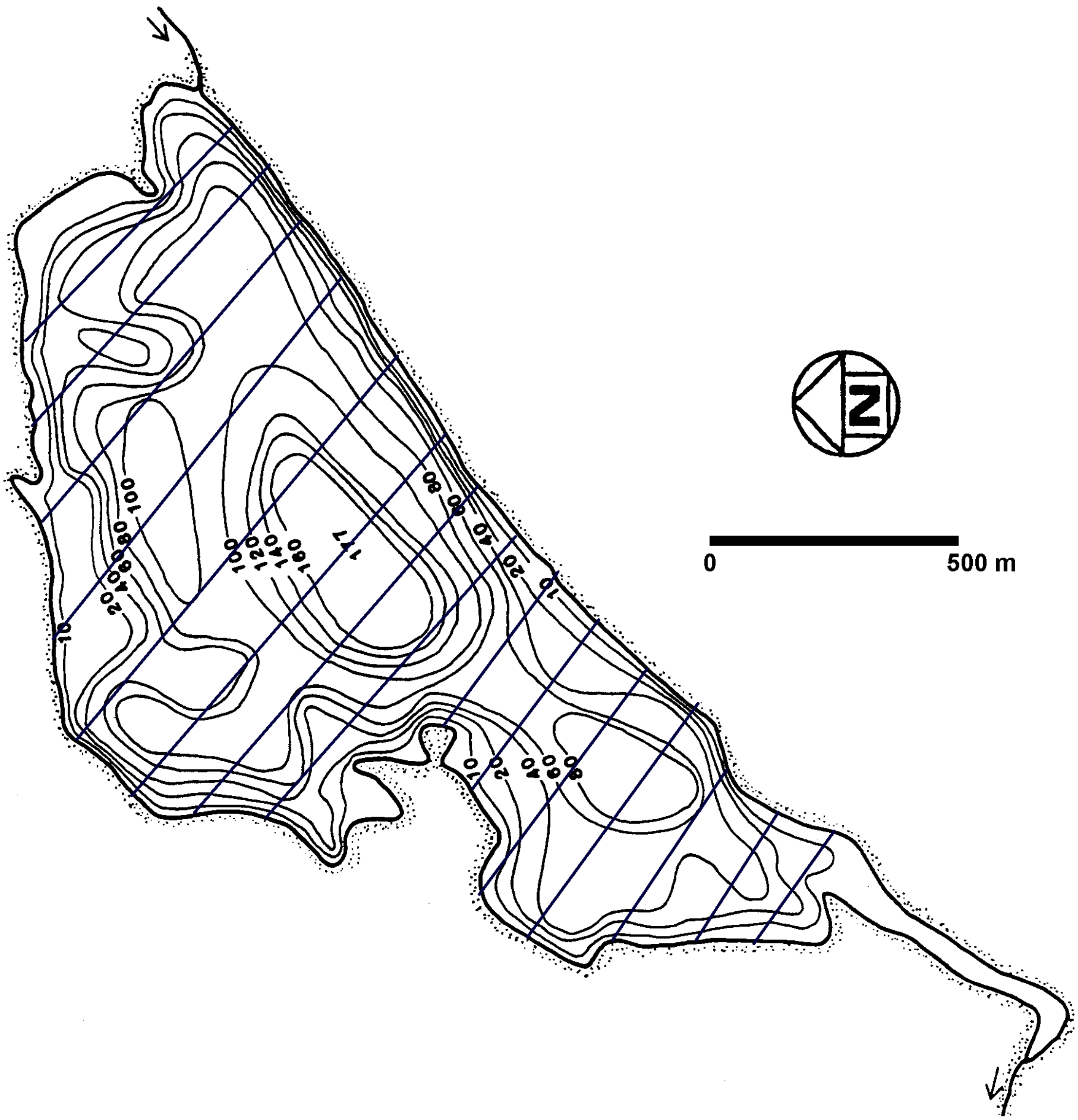
Appendix D3.–Historical fish densities for Larson Lake by depth.



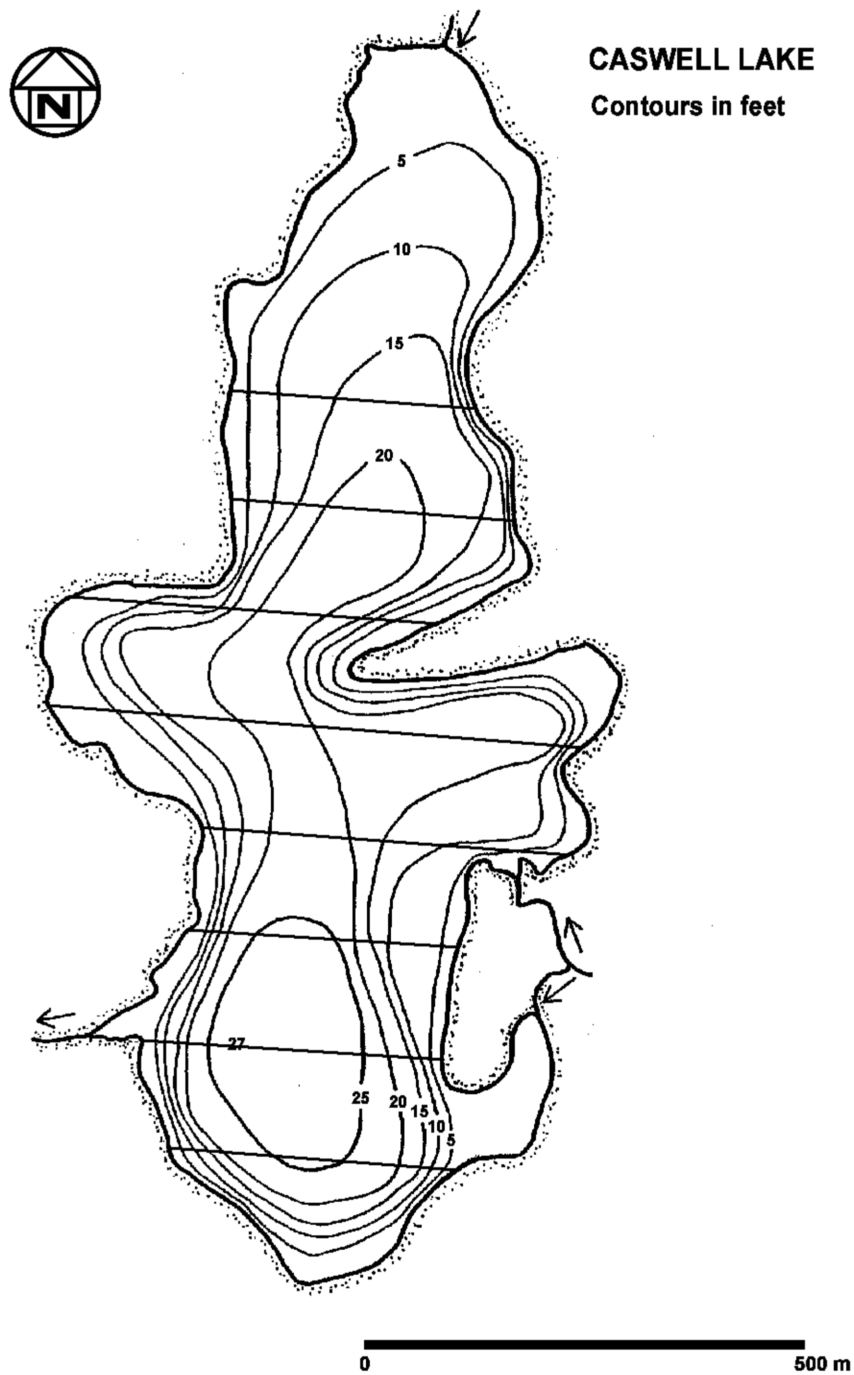
Appendix D4.–Historical fish densities for Shell Lake by depth.

APPENDIX E: LAKE MAPS

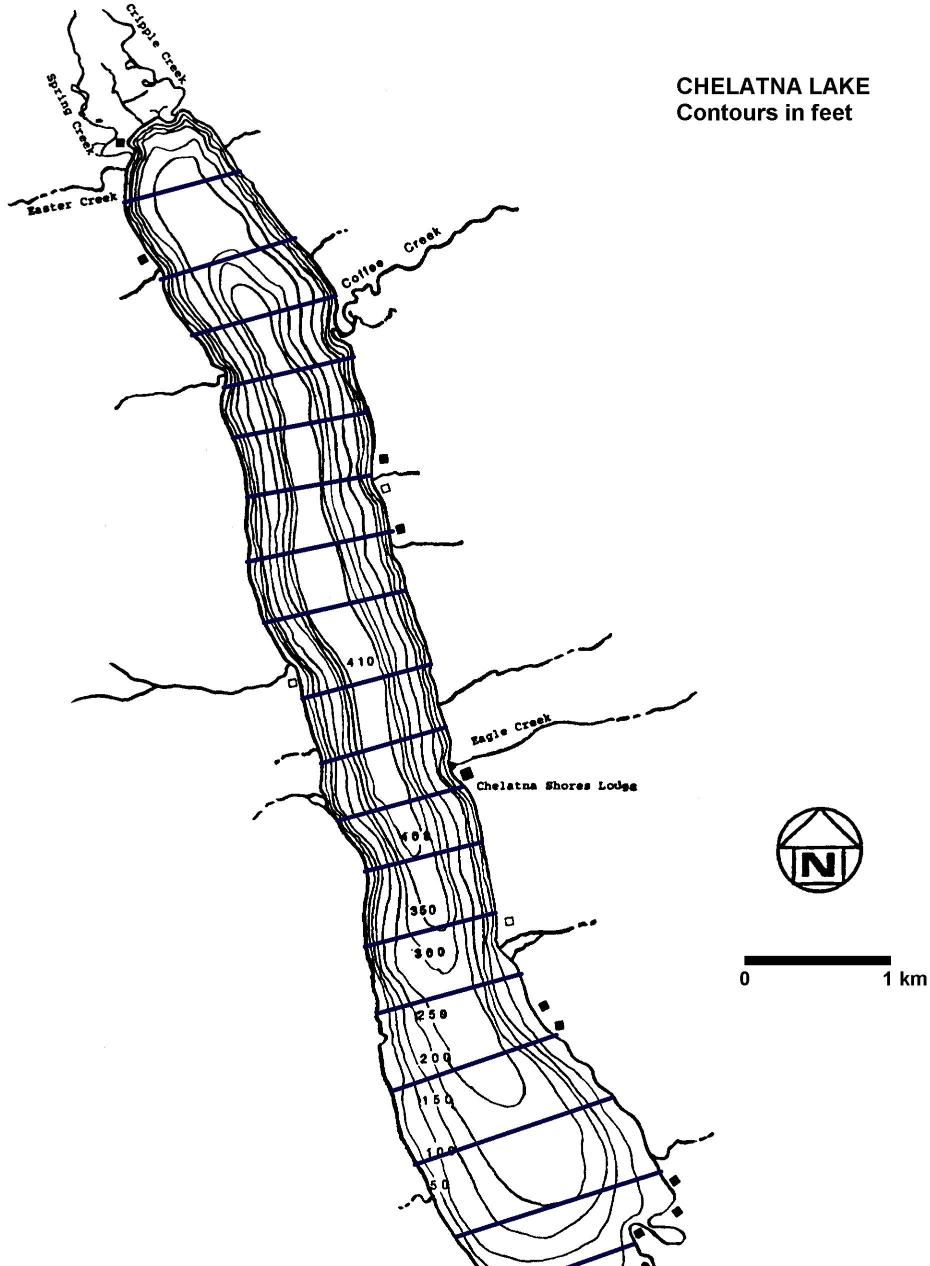
BYERS LAKE
Contours in feet



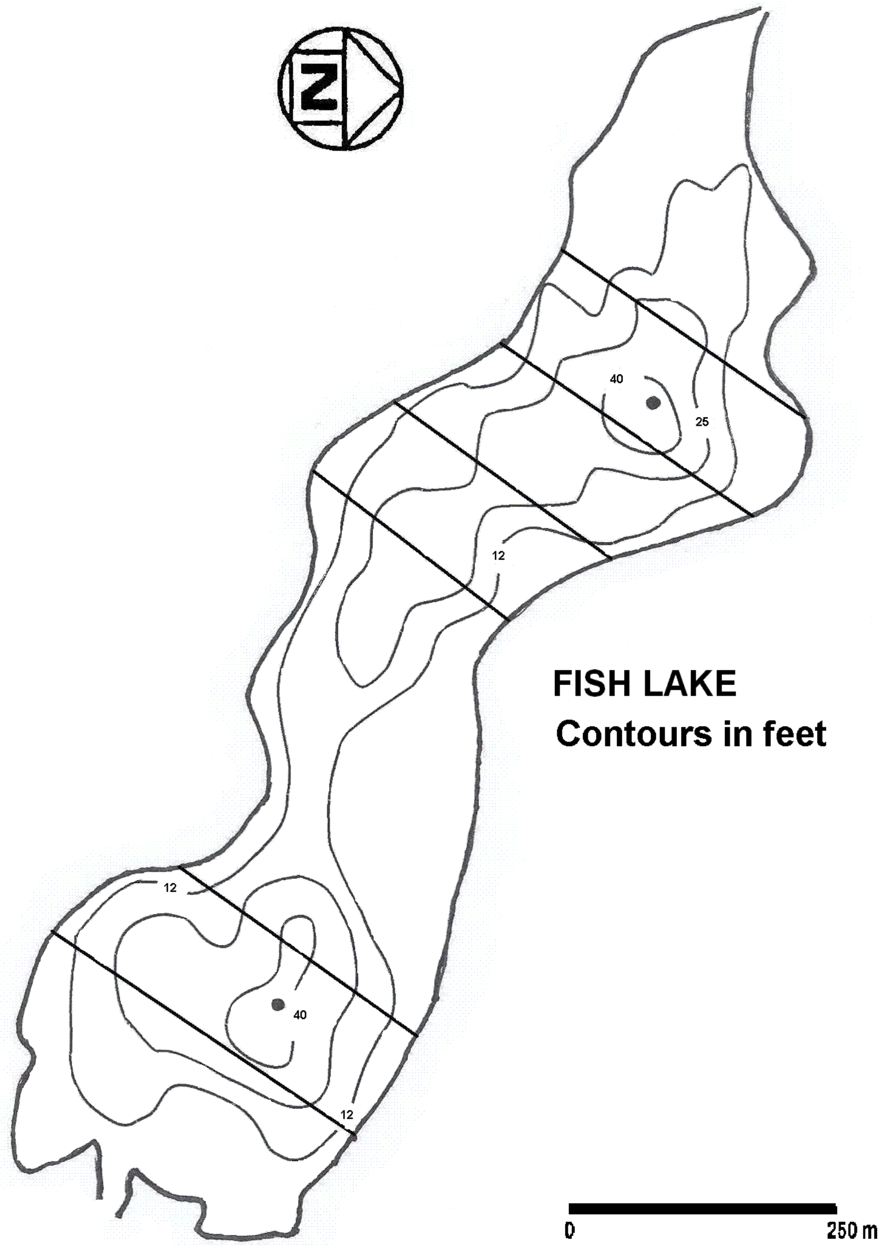
Appendix E1.–Byers Lake bathymetry and hydroacoustic transects.



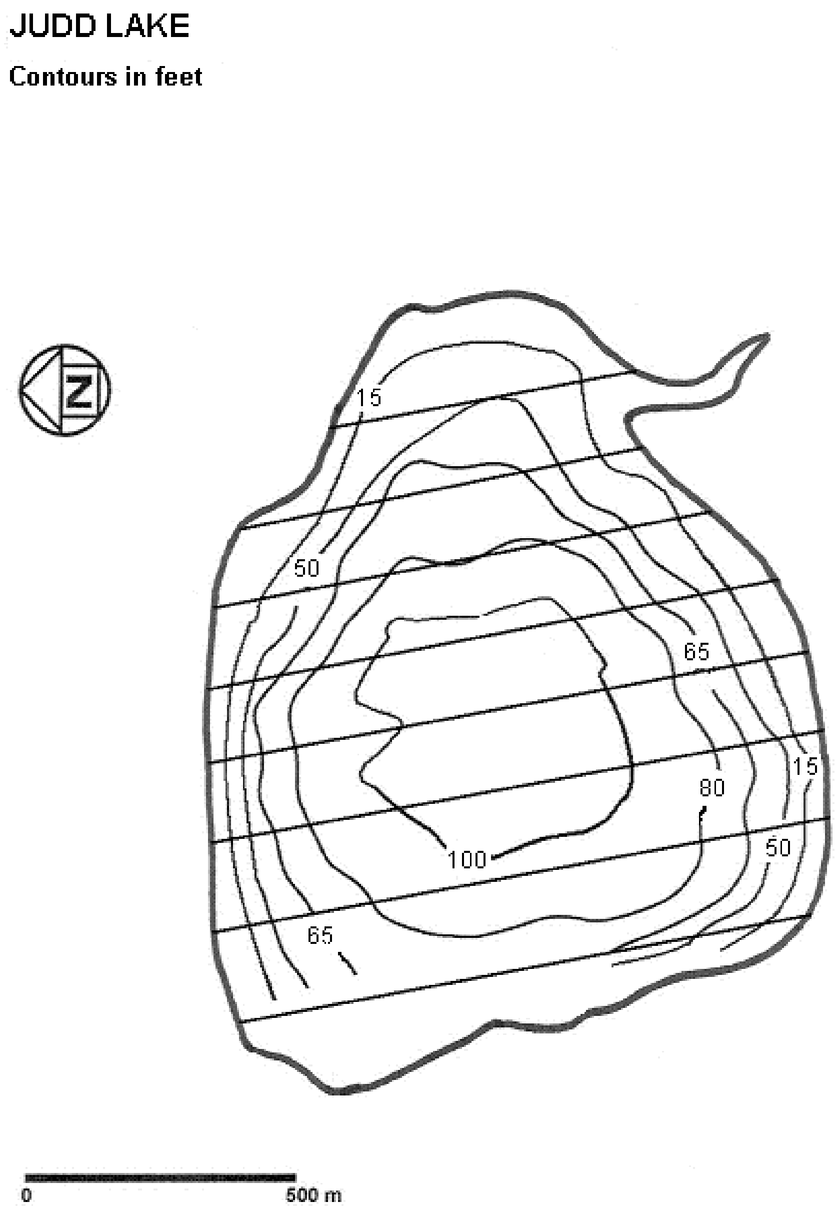
Appendix E2.–Caswell Lake bathymetry and hydroacoustic transects.



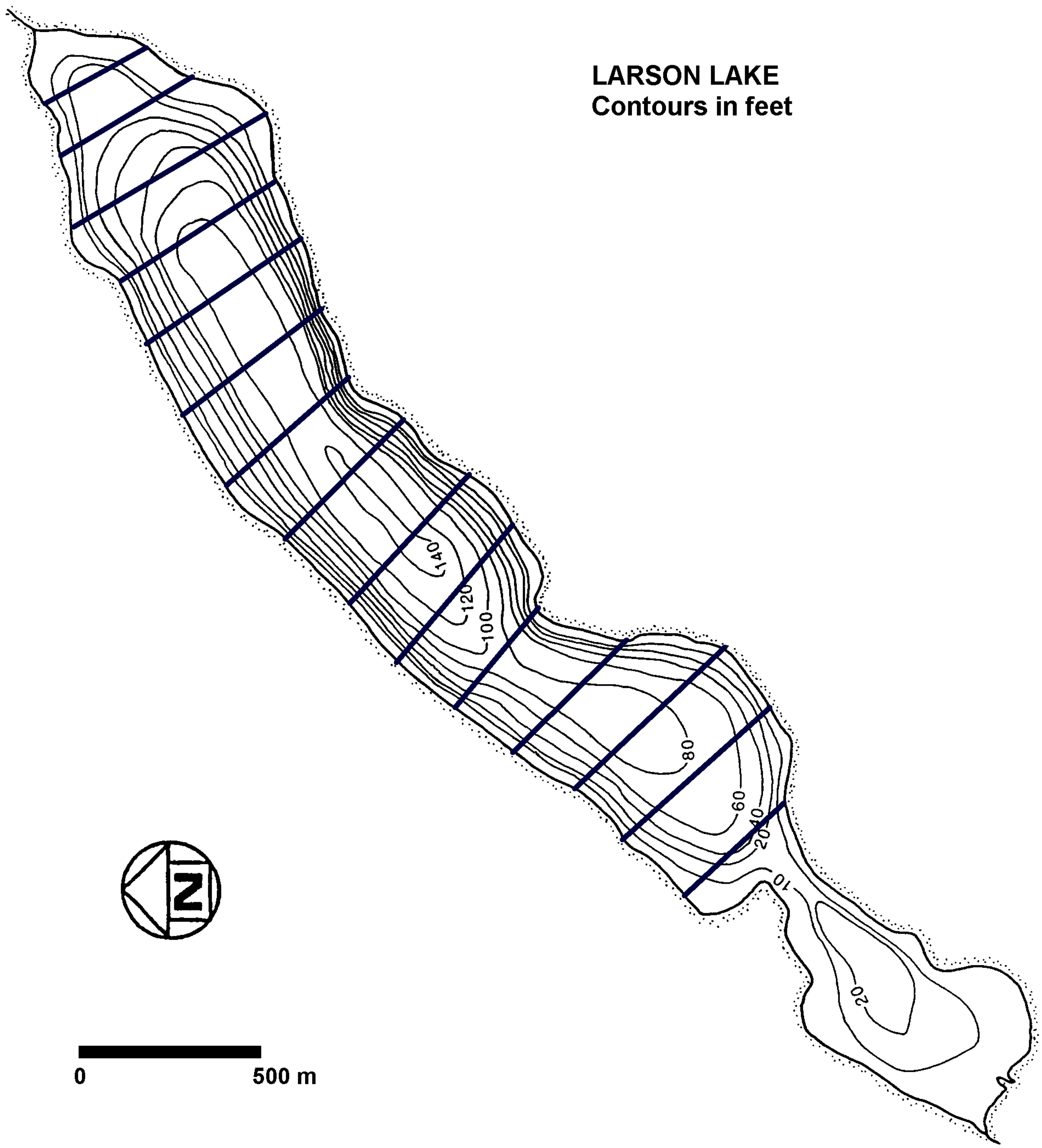
Appendix E3.–Chelatna Lake bathymetry and hydroacoustic transects.



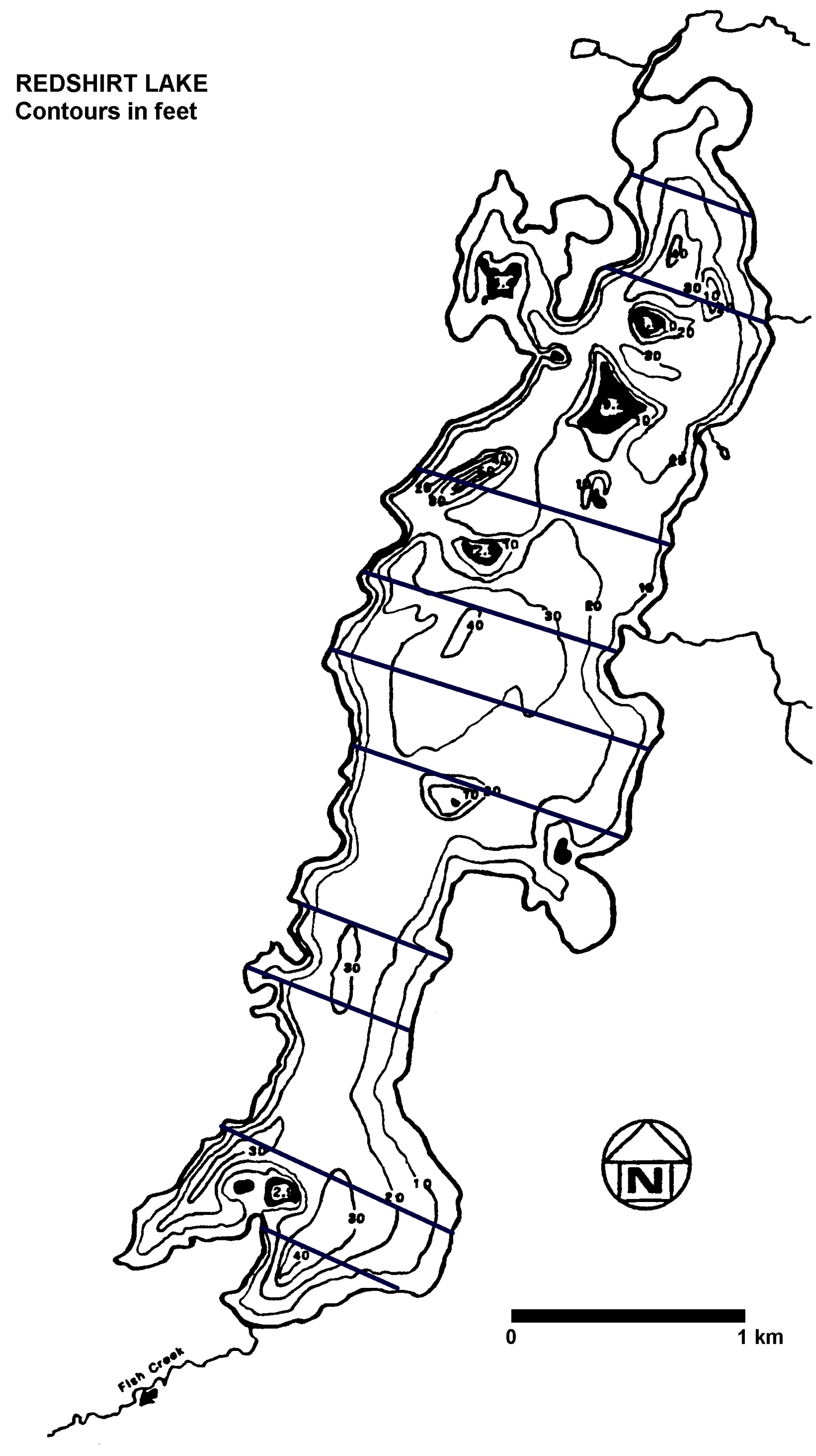
Appendix E4.–Fish Lake bathymetry and hydroacoustic transects.



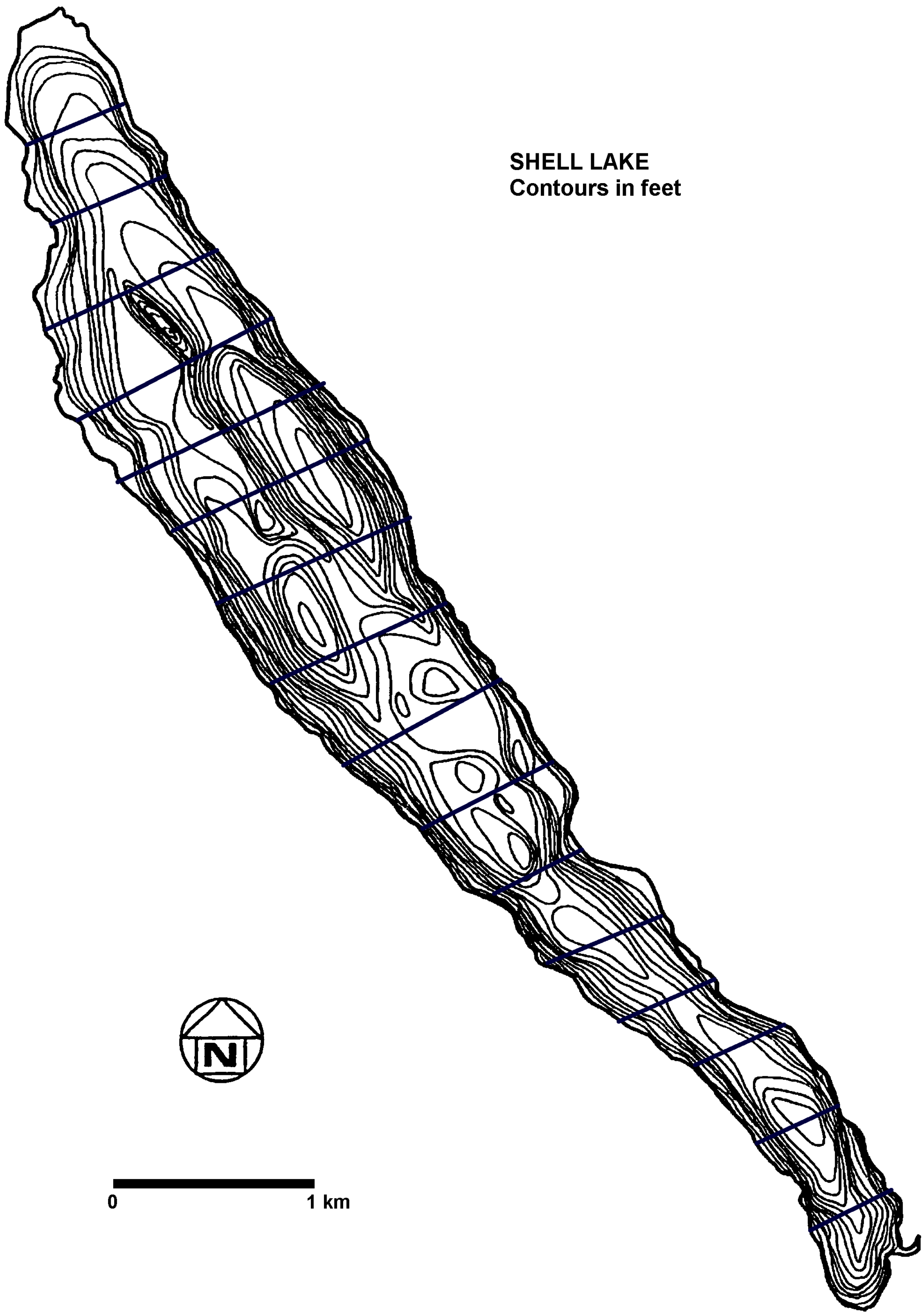
Appendix E5.–Judd Lake bathymetry and hydroacoustic transects.



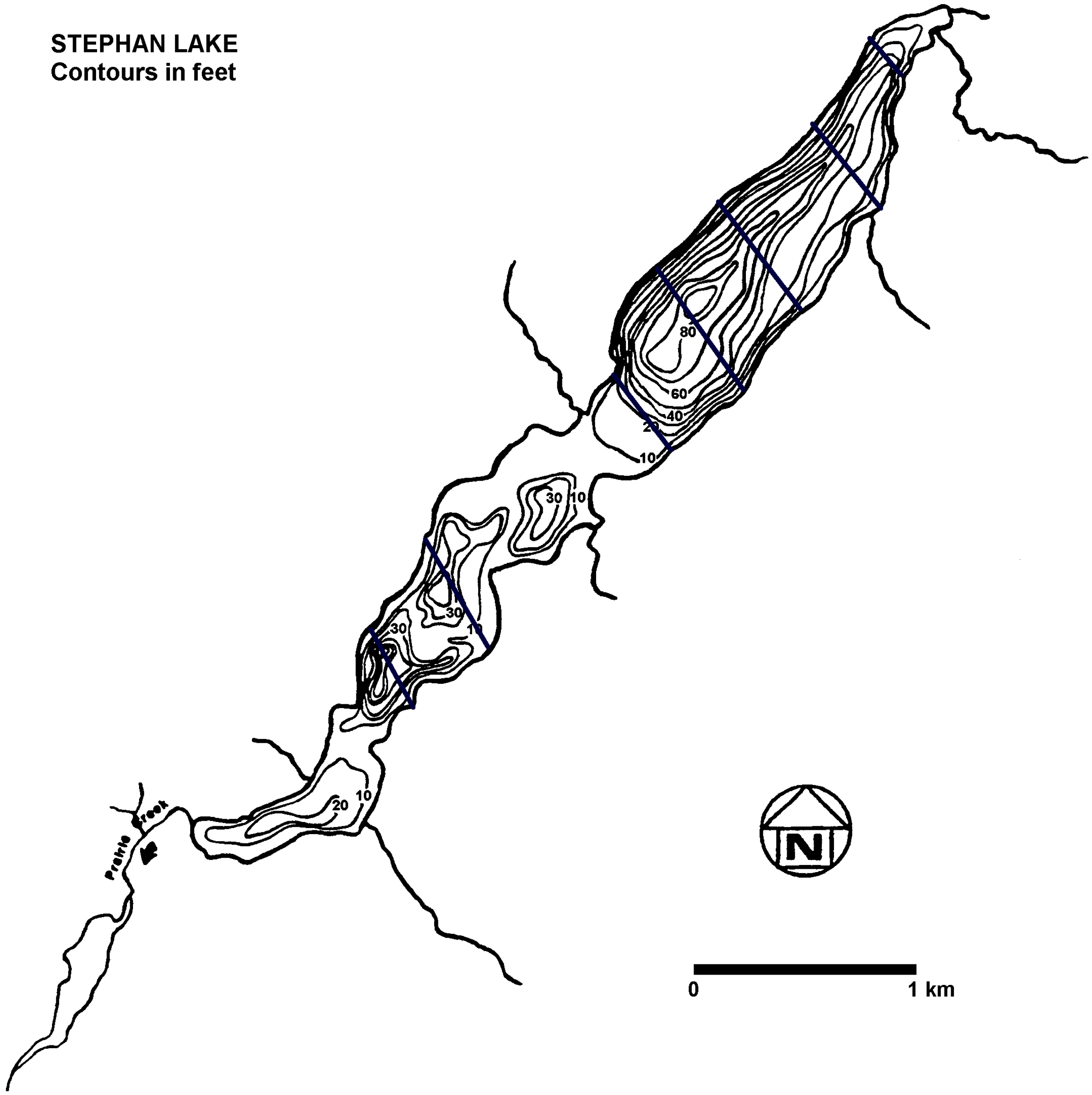
Appendix E6.–Larson Lake bathymetry and hydroacoustic transects.



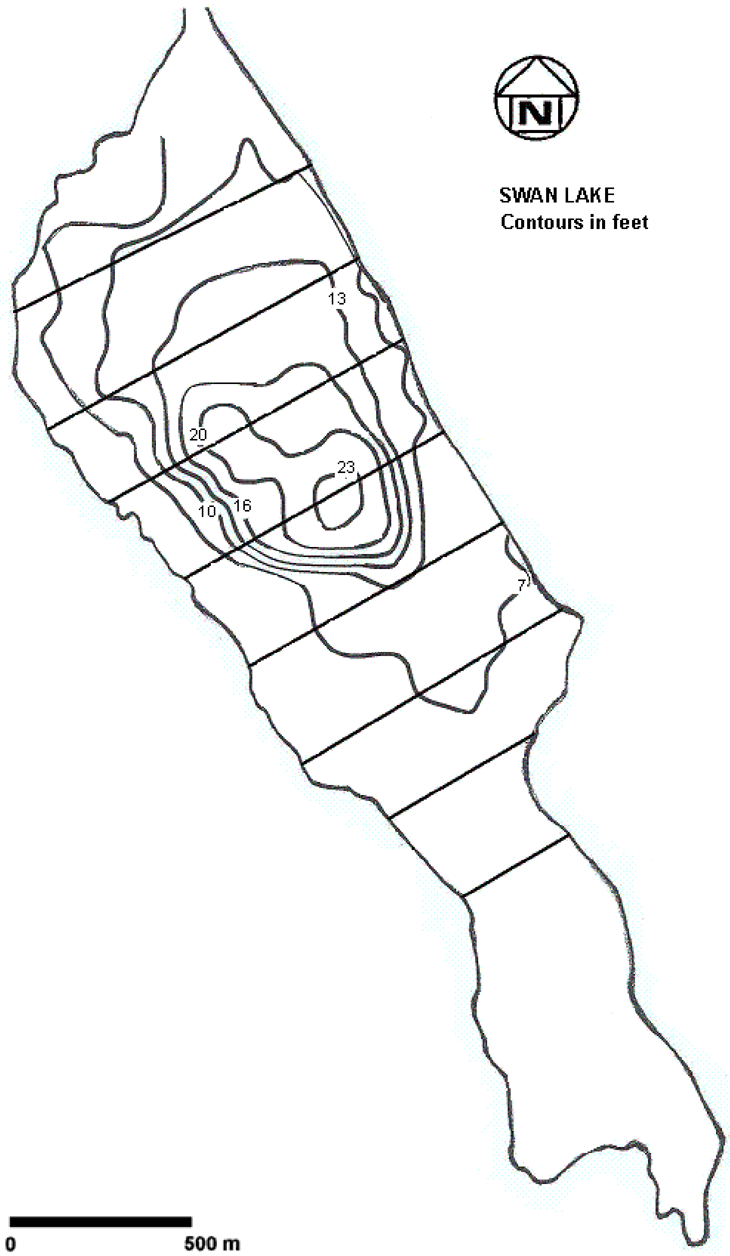
Appendix E7.–Redshirt Lake bathymetry and hydroacoustic transects.



Appendix E8.–Shell Lake bathymetry and hydroacoustic transects.

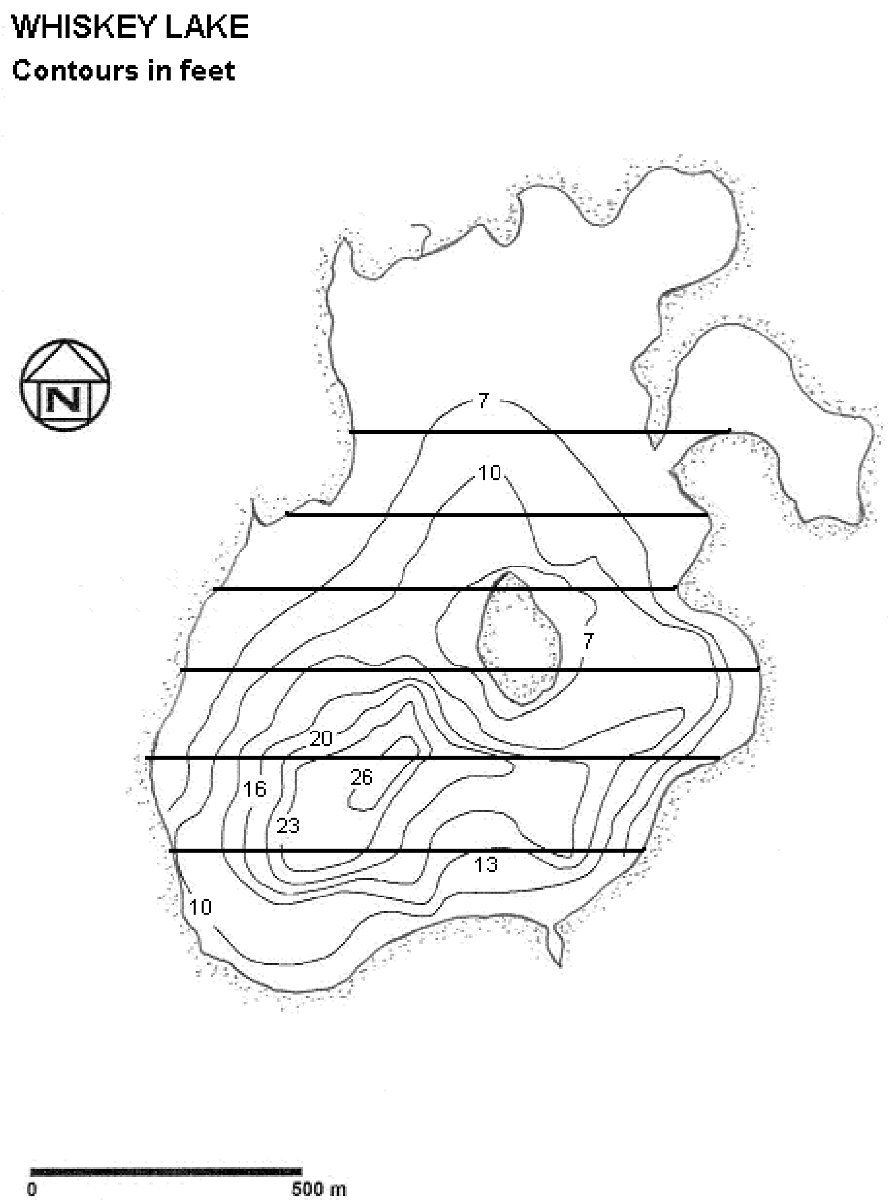


Appendix E9.–Stephan Lake bathymetry and hydroacoustic transects.



Appendix E10.–Swan Lake bathymetry and hydroacoustic transects.

Appendix E11.–Trapper Lake bathymetry and hydroacoustic transects.



Appendix E12.–Whiskey Lake bathymetry and hydroacoustic transects